NASA TECHNICAL MEMORANDUM

April 1974

NASA TM X-64810

MSFC SKYLAB AIRLOCK MODULE
Vol. II

Skylab Program Office

NASA

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

(NASA-TM-X-64810-Vol-2) MSFC SKYLAB AIRLOCK MODULE, VOLUME 2 Final Report (NASA) 652 p HC $11.00 CSCL 22B

N74-26338

Unclas
G3/31 40152

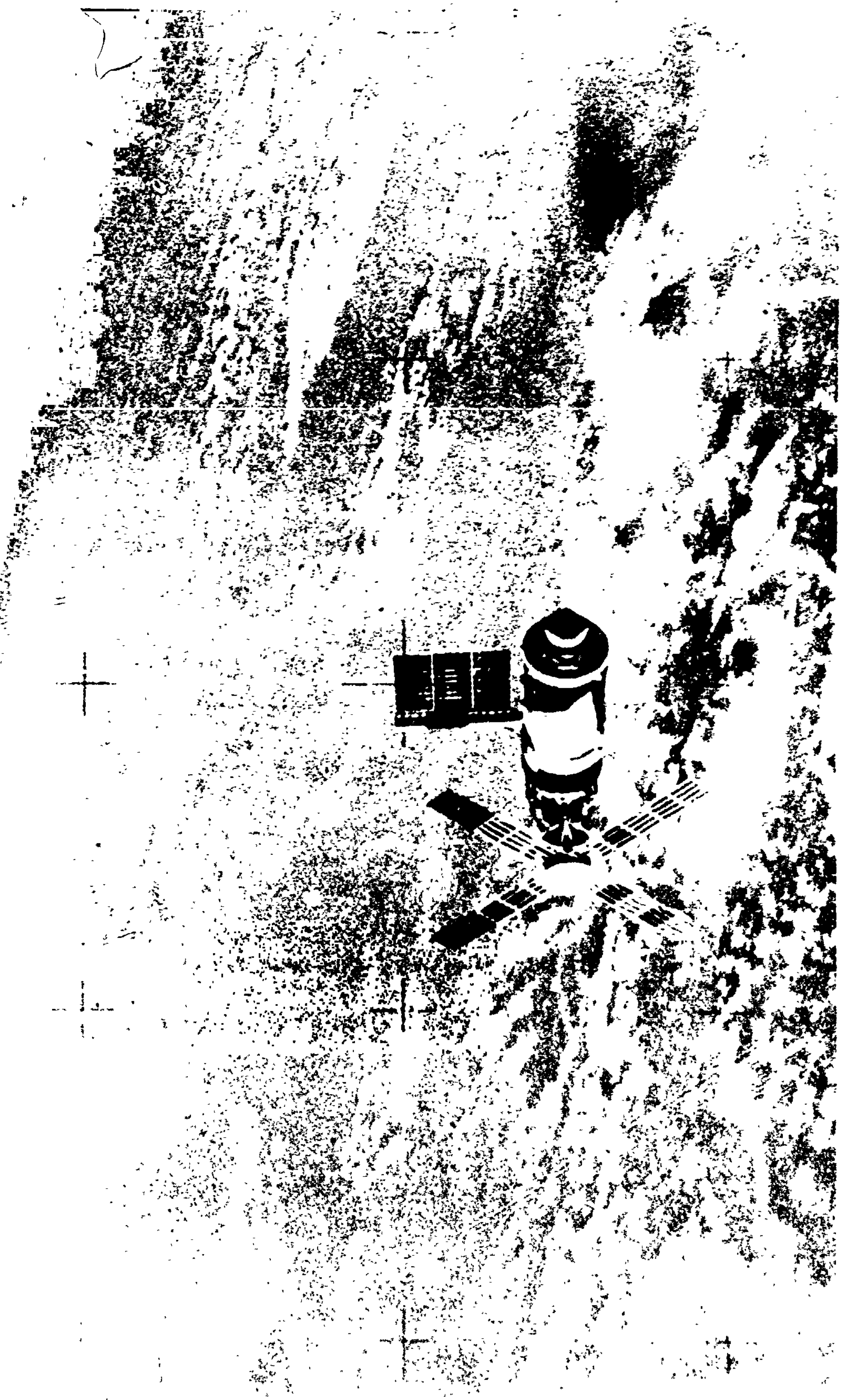


TABLE OF CONTENTS

VOLUME I

TABLE OF CONTENTS VOLUME I CONTINUED

TABLE OF CONTENTS VOLUME I AND II

VOLUME II

TABLE OF CONTENTS VOLUME II CONTINUED

TABLE OF CONTENTS VOLUME II CONTINUED

TABLE OF CONTENTS VOLUME II CONTINUED

* NOTE: The Final Technical Report for the Payload Shroud is presented in MDC Report G4679A.

LIST OF FIGURES

LIST OF FIGURES CONTINUED

LIST OF FIGURES - CONTINUED

LIST OF FIGURES CONTINUED

LIST OF FIGURES CONTINUED

LIST OF FIGURES CONTINUED

LIST OF FIGURES CONTINUED

LIST OF FIGURES CONTINUED

LIST OF FIGURES CONTINUED

LIST OF FIGURES CONTINUED

LIST OF FIGURES CONTINUED

LIST OF FIGURES CONTINUED

LIST OF FIGURES CONTINUED

LIST OF FIGURES CONTINUED

This document consists of the following pages:

VOLUME I

Title Page
iii through xxiii
1-1 through 1-22
2.1-1 through 2.1-12
2.2-1 through 2.2-32
2.3-1 through 2.3-6
2.4-1 through 2.4-124
2.5-1 through 2.5-123
2.6-1 through 2.6-56
2.7-1 through 2.7-146
2.8-1 through 2.8-64
2.9-1 through 2.9-44

VOLUME II

Title Page
iii through xxiii
2.10-1 through 2.10-78
2.11-1 through 2.11-26
2.12-1 through 2.12-64
2.13-1 through 2.13-28
2.14-1 through 2.14-12
2.15-1 through 2.15-54
2.16-1 through 2.16-18
3-1 through 3-20
4-1 through 4-12
5-1 through 5-40
6-1 through 6-42
7-1 through 7-44
8-1 through 8-4
9-1 through 9-14
A-1 through A-20
B-1 through B-14
C-1 through C-24
D-1 through D-12
E-1 through E-16
F-1 through F-12
G-1 through G-8
H-1 through H-8
I-1 through I-4
J-iii through J-65

2.10 COMMUNICATIONS SYSTEM

The Communications System was required to send and receive information between:

- Crew members in the SWS (AM/MDA/OWS) or on EVA.
- Crew members and STDN.
- SWS Systems and STDN.
- AM and CM during rendezvous.

Information originating in the SWS, which consisted of voice, instrumentation data, and television, necessitated downlink transmission to STDN in both real-time and delayed-time. The AM transmitters were needed for real-time and delayed-time transmission of telemetry data and for delayed-time voice. The CM transmitters were used for SWS real-time voice and for real-time and delayed-time television. Voice and command message uplink information was received from STDN, the command link via AM receivers, the voice via CM receivers. The commands were decoded in the AM and used in the SWS to control on-board equipment, to update timing, and to provide printed messages via a teleprinter. To facilitate CSM to SWS rendezvous, a VHF ranging system was provided on the AM which transponded ranging information to the CM. AM tracking lights were provided to facilitate visual acquisition of the SWS during rendezvous.

In fulfillment of the foregoing basic communication needs, the design effort identified the subsystem equipment required, either newly designed, off-the-shelf, or modified. Specific requirements which governed equipment design and operation included the following:

- Compatibility with existing STDN and CM equipment.
- Maximum use of existing flight qualified equipment.
- Redundancy to assure mission success.
- Capability of in-flight replacement of selected hardware.
- Maximum use of ground control over equipment operation with crew control backup.
- Minimum encumberance to the crew.
- Antenna coverage for all mission phases.
- A goal that the electronics design be neither the source of nor susceptible to EMI. (Reference paragraph 2.16.1).

As equipment selection was customer approved, the equipment's pertinent characteristics became requirements.

For discussion purposes the Communications System is divided into subsystems as follows:

- Audio.
- Data transmission and antenna.
- Digital command, teleprinter, and time reference.
- Rendezvous.

This subsystem equipment along with major interfaces are shown in block diagram form in Figure 2.10-1. In addition to the above subsystems, a GFE supplied television input station (TVIS) and radio noise burst monitor (RNBM) antenna were installed on the AM.

Verification of the Communications Systems design requirements was successfully completed during the course of the testing program. The testing phase employed a comprehensive program of tests beginning at the component level in-house and at vendor facilities and continuing through module interface, system, systems interface, systems integration and systems support mode, with completion of the checkout cycle at the launch site facility. At the contractor facility, the evaluation and verification of system performance was accomplished during subassembly tests and the major tests as shown by Figure 2.10-2. These tests verified each system individually and culminated with all systems being tested collectively with the MDA and associated experiments. Launch site test requirements for the Communications System were defined in MDC Report E0122, Test and Checkout Requirements Specifications and Criteria, for use at KSC, and by the Skylab Integrated System Test Checkout Requirements and Specifications, Document No. TM 012-003-2H. These test requirements were successfully accomplished during the course of system level and integrated testing at KSC. The system test flow followed at KSC is shown in Figure 2.10-3.

Mission problems or suspected problems were usually resolved by engineering analysis; however, some hardware problems required use of the Electronics Skylab Test Unit (STU) or the AM/MDA U-2 vehicle for operational configuration simulation or modification kit development and validation. The AM/MDA U-2 communications system equipment was functionally identical to AM/MDA U-1 and was powered up for significant mission events as well as for problem investigations.

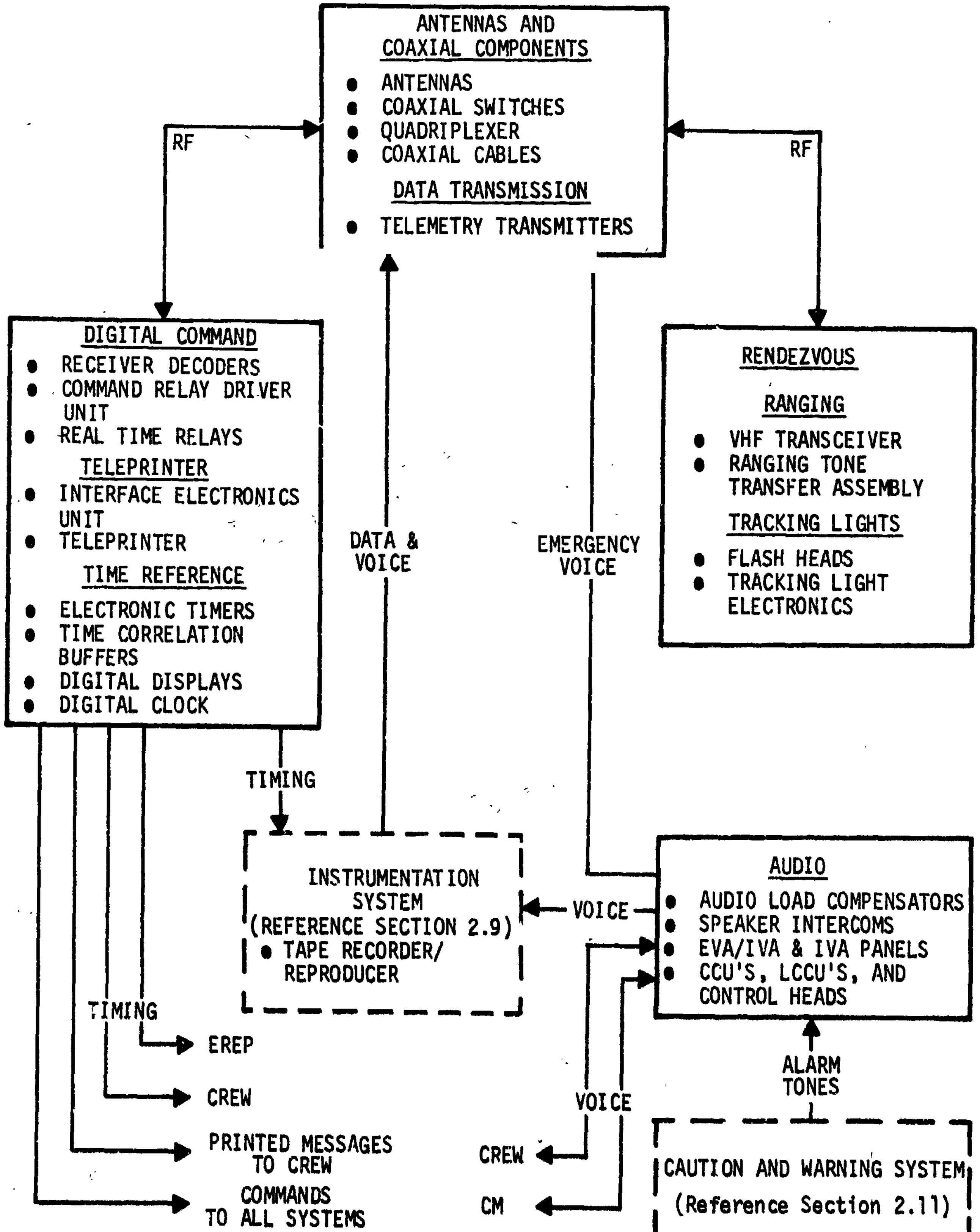


FIGURE 2.10-1 COMMUNICATIONS SYSTEM

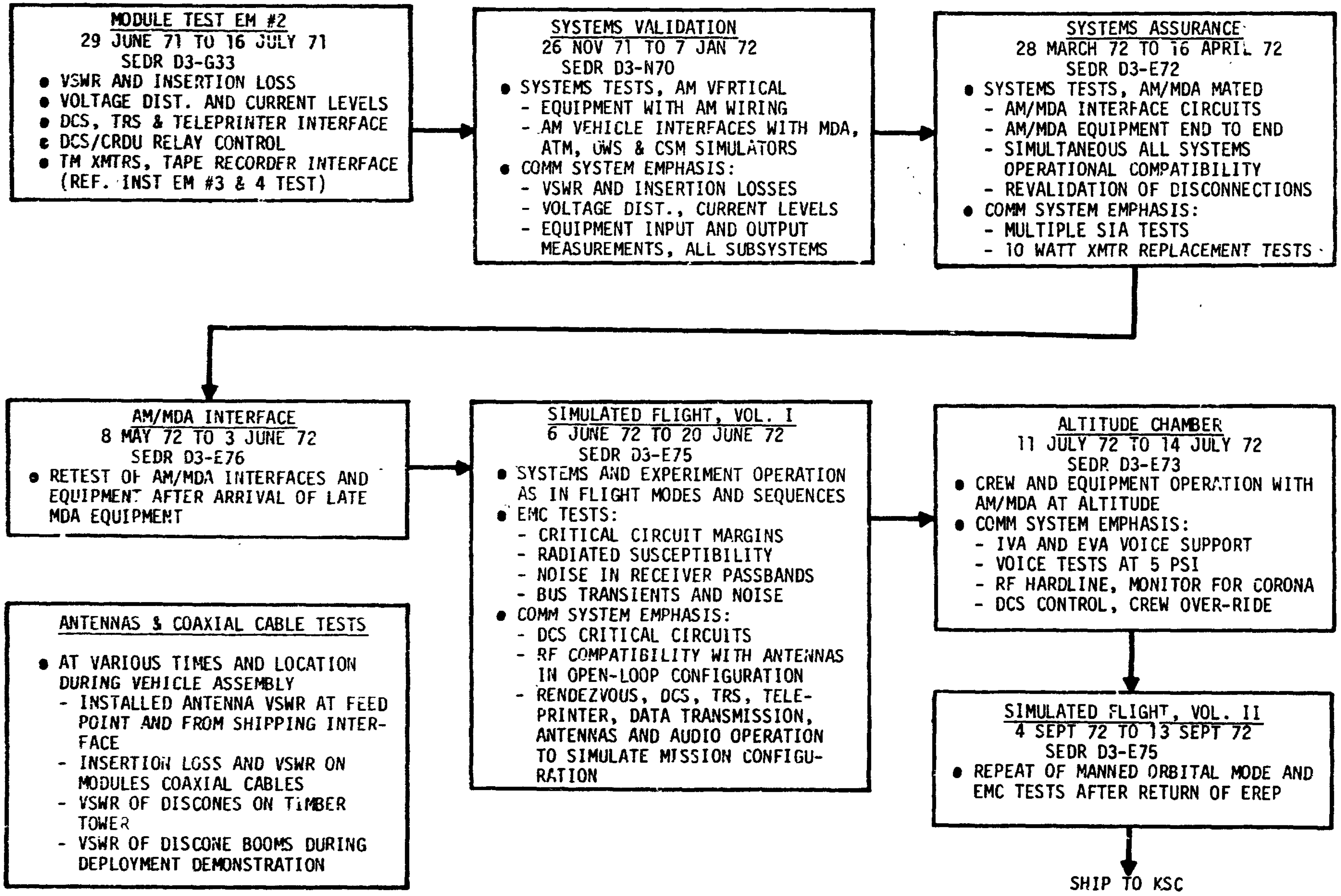


FIGURE 2.10-2 COMMUNICATIONS SYSTEM TEST FLOW – MDAC-E

FROM ST. LOUIS TO MSOB

AM/MDA INTEGRATED SYSTEMS
21 OCT 72 TO 1 DEC 72
KM0003
- SYSTEMS OPERATION AND COMPATIBILITY REVERIFICATION
- VSWR RETEST OF COAXIAL CABLES
- AUDIO, DCS, TELEPRINTER, TM, TRS, TV, TRACKING LIGHTS AND RANGING FUNCTIONAL TESTS
  - DCS CONTROL AND LOCKOUT
  - AUDIO INTERFACE WITH CREW SUITS, RECORDERS AND C&W

CSM-AM/MDA INTERFACE AND DOCKING
11 DEC 72 TO 19 DEC 72
KM0001
- INTERFACE COMPATIBILITY WITH CSM DOCKED TO MDA (ELECTRICAL MATE)
- ORBITAL MISSION SIMULATION
- COMM SYSTEM TESTS INCLUDED:
  - AUDIO & TV VIA CSM TO STDN
  - EVA/IVA SUITED CREW VOICE TEST
  - DCS CONTROL OF CSM FUNCTIONS
  - AM/CSM RANGING VIA DELAY UNIT
  - DATA TRANSMISSION TO STDN

DA FUNCTIONAL AND EXPERIMENTS
11 JAN 73 TO 14 JAN 73
KM0002
- VERIFY WIRE BUNDLES FROM AM/MDA TO ATM ON THE DA
- VERIFY COMMUNICATIONS EQUIPMENT:
  - ANTENNAS AND COAX CABLES VSWR
  - DISCONE TEST WITH DCS AND TM
  - RANGING ANTENNA RADIATION TESTS
  - RF CHECK OF BOTH STUB ANTENNAS
  - TV AND TRACKING LIGHTS CHECKED
  - RNBM END TO END WITH NOISE SOURCE

MOVE TO VAB

SWS END TO END SYSTEMS
9 FEB 73 TO 25 FEB 73
KS0003 AND KS0045
- COMBINED SWS SYSTEMS TEST
- OWS AND ATM INTERFACE VERIFICATION
- COMM SYSTEM TESTS INCLUDED:
  - ANTENNAS CHECKED WITH PARASITIC TO ROOF-TOP ANTENNAS
  - TM, DCS AND RANGING RF OPEN-LOOP TESTS VAB/MSOB
  - FUNCTIONAL TEST OF DCS, TELEPRINTER AND TRS WITH SYSTEM INTERFACES VERIFIED
  - AUDIO AND TV (COLOR) TESTED FROM ALL SWS LOCATIONS

SV OAT AND SIM. FLIGHT
14 MAR 73 TO 26 MAR 73
KS0002
- SV COMPATIBILITY AND SWS SYSTEMS ORBITAL OPERATIONS
- ALL COMM SUBSYSTEM SUPPORT
- RANGING TO CSM ON PAD 39B

SWS COUNTDOWN
27 APRIL 73 TO 14 MAY 73
KS0007
- TM XMTRS, DCS AND TRS WERE OPERATED AS REQUIRED FOR PRE-LAUNCH TESTS AND SL-1 LAUNCH

OTHER SWS TESTS THAT REQUIRED COMMUNICATIONS SYSTEM SUPPORT:

- AM/MDA/OWS ELECTRICAL INTERFACE, 31 JAN 73 TO 8 FEB 73 (KS0003)
- SWS TO IU INTERFACE, 23 FEB 73 (KS0004)
- SWS OPERATIONS FOR SV SWING ARM OAT, 27 FEB 73 (KS0008)
- SWS FLIGHT SYSTEMS REDUNDANCY, 27 AND 28 MAR 73 (KS0011)
- SWS OPERATIONS FOR LV FRT, 28 MAR 73 (KS0011)
- AM/MDA/OWS STANDARD POWER UP AND POWER DOWN (KS1003)
- SWS ELECTRICAL AND MECHANICAL CLOSEOUT - (RETEST OF COAXIAL SWITCHES) (KS0016)
- SWS OPERATION FOR TRANSFER TO PAD (KS0018)

FIGURE 2.10-3 COMMUNICATIONS SYSTEM TEST FLOW – KSC

2.10.1 Audio Subsystem

2.10.1.1 Audio Subsystem Design Requirements

The Skylab audio subsystem was required to provide voice intercommunications to three crewmen within the orbital assembly (OA) and/or while engaged in extra-vehicular activity, and to provide air to ground duplex voice communications between the crewmen and the STDN. A later requirement was added to provide recording of voice for delayed transmission to the ground.

2.10.1.2 Audio Subsystem Description

The following paragraphs present the evolution of design changes that occurred to the audio subsystem as the Skylab program progressed from its initial concept to the final flight configuration. These design changes were necessary to comply with the design requirement revisions that had occurred as the needs of the audio subsystem expanded. The audio subsystem required four major revisions in order to arrive at the final flight configuration.

A. The initial audio subsystem was comprised of a Gemini voice control center, three hardline crewmen umbilical disconnects, and two Gemini VHF voice transceivers, one of which was modified by retuning the receiver. The transmitter in the modified unit was not used. In addition, the crewman headset assemblies were to be Gemini type. The umbilical disconnects were to be located in the Airlock, forward tunnel, and aft tunnel, and were interconnected via an audio distribution system, to the voice control center which provided the necessary amplification and switching control to provide sidetone, modulation, and reception of the VHF transceivers. The VHF transceivers provided communications between the AM and the docked CM, and between the AM and the STDN. In addition, the VHF transceivers provided communications between crewmen located in the Airlock and crewmen operating from the proposed EVA portable life support system (PLSS) backpack transceivers.

B. The first major change to the audio system added an audio control unit and two portable speaker intercom assemblies. The audio control unit was required to provide impedance matching to enable the crewmen to utilize Apollo-type headset assemblies and to allow the Airlock hard-line distribution system to interface with the Apollo audio system.

The hardline audio distribution system (ADS) was expanded to provide crewmen umbilical disconnects throughout the CM, LM, MDA, AM, and OWS. The primary voice mode utilized the ADS in conjunction with the Apollo voice communication system to provide communications among the crewmen and between the crewmen and the STDN. The subsystem also included a secondary voice mode which utilized the ADS in conjunction with the Airlock VHF transceivers, voice control center and audio control unit, to provide intercom for the crewmen and a VHF simplex link between the Airlock and the STDN. The selection of the primary or secondary voice systems was made by properly positioning jumper cables located in the CM and STS. A backup voice duplex VHF link was also available which permitted emergency voice communications between the AM and crewmen using the PLSS. Two portable speaker intercom assemblies were available and could be connected to any communication disconnect throughout the cluster should headset operation be undesirable.

C. The second major change deleted the Airlock RF voice communication subsystem and added a redundant hardline audio distribution system, two audio load compensators, and three additional speaker intercom assemblies. The deleted equipment included the VHF transceiver, VHF duplex receiver, voice control center, and the audio control unit. This deletion resulted in the incorporation of a redundant ADS, with each ADS connected to a command module audio center. Each ADS included an audio load compensator (ALC) which provided amplification, isolation, and impedance matching between the SWS and the CM. In addition, the ALC provided a separate amplified output to allow for modulation of track B of the AM tape recorder to provide voice recording capability. The audio subsystem then included five portable speaker intercom assemblies that could be connected to any crewman communication disconnect located throughout the cluster.

D. The third major change to the audio subsystem increased the speaker intercom assemblies (SIA) from five units to eleven units, installed the SIA's in predetermined permanent locations and incorporated circuitry within the SIA's to enable interface with the Caution and Warning system for the purpose of providing visual and audible caution and warning alerts. Each SIA provided the capability of selection

between each ADS (CH A or B), a sleep switch to interrupt earphone/speaker audio circuits for a sleeping crewman, tape recorder enable switching, a call switch to activate all SIA stations regardless of channel selected, and Cahnnel A and Channel B individual crewman communication umbilical disconnects.

E. The final major configuration change increased the SIA quantity from eleven units to fifteen units. Thirteen units were to be operational and installed in predetermined locations throughout the SWS in such a manner that any SIA could be replaced with the flight spares. The final flight audio subsystem configuration also included two EVA panels, one IVA panel, two audio load compensators (ALC), eight lightweight crewman communication umbilicals, four crewman comm control heads, and three crewman communication umbilicals. The audio subsystem contained redundant audio channels, A and B, and was configured as shown in Figure 2.10-4. This configuration provided redundant voice communication throughout the SWS. Voice modulation input into an SIA microphone, a headset assembly, or an EVA/IVA panel was routed through either the Channel A or Channel B ALC. The ALC connected to the selected channel received the voice signal and amplified and routed the signal to the CM audio center where the signal was further amplified and compressed. The audio was then applied to the CM S-band or VHF transmitters for transmission to the STDN on receipt of an SWS transmit key function. The CM audio center earphone amplifier received both the compressed microphone line audio and the STDN uplink audio. Its output signal was then applied to the AM ALC earphone amplifier and tape recorder amplifier inputs. The ALC earphone line amplifier provided isolation and impedance matching to the SWS earphone line which in turn was connected to the SIA(s) speaker amplifier, EVA/IVA panel earphone circuits and/or a SIA-connected headset assembly. The ALC tape recorder amplifier provided isolation and additional amplification and compression to properly modulate the Track B input of the AM tape recorders. An emergency communication configuration was available to the crew by disconnecting the umbilical connections for Channel A and B at the CM/MDA interface, installing supplied jumper plugs

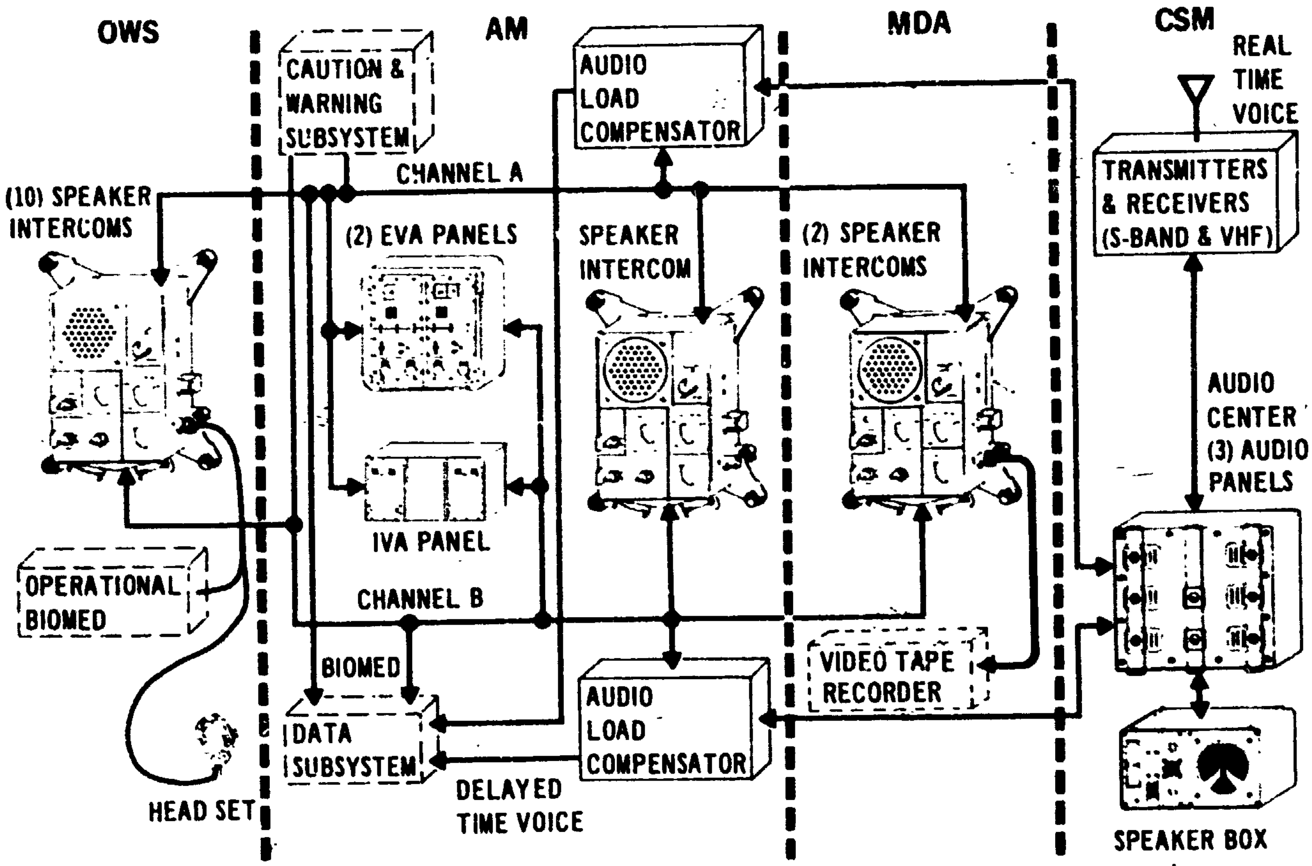


FIGURE 2.10-4 ORBITAL ASSEMBLY AUDIO SYSTEM

to the MDA receptacles, disconnecting a tape recorder and installing a supplied jumper plug to the selected tape recorder in-line cable disconnect. This configuration enabled the crew to maintain voice communications throughout the SWS and provided voice modulation to a selected AM telemetry transmitter for downlink communications. Emergency uplink communications was provided via the teleprinter.

Late in the Skylab Program a video tape recorder (VTR) was added to the onboard television system. It was desired to provide synchronization of recorded TV pictures and the accompanying voice comments. Therefore, the capability to record audio on the VTR was added. The VTR was designed to accept the earphone line audio at an SIA CCU connector. The AM audio system did not require modification to incorporate this change.

The following presents the SWS audio subsystem primary electrical characteristics and functions:

A. Speaker Intercom Assembly
- Speaker and microphone circuitry selectable between Channel A and B.
- Channel A and B crewman communication umbilical (CCU) disconnects.
- Sleep mode to provide interruption of speaker and CCU earphone and caution and warning tone circuitry.
- Call function to enable both Channel A and B microphone circuits simultaneously, override sleep mode of other SIA's and headsets, and provide fixed volume level of SIA's.
- Redundant caution and warning tone circuitry for headset and speaker functions and visual alarm indicator.
- Bio-med interface between the CCU and the instrumentation system.
- Separate intercommunication or transmit key function.
- Voice recorder enable function with visual record enable indicator.

B. Audio Load Compensator
- Redundant microphone line amplifiers with a nominal voltage gain of 2 dB.
- Redundant earphone line amplifier with a nominal voltage gain of 3 dB into 600 ohms.
- Automatic gain controlled tape recorder amplifier to provide a constant modulation level to the AM tape recorders.

C. EVA/IVA Panels
- Electrical disconnects which provided either Channel A or B earphone and microphone lines.
- Redundant DC power.
- Bio-Med Interface.

D. Crewman Communication Umbilical
- Interface between an SIA Channel A or B CCU disconnect and crew pressure garment assembly.
- Microphone, earphone, and caution and warning tone lines.
- Earphone line volume control.
- Transmit and intercom function switch.
- Bio-Med lines.
- Length - 180 inches.

E. Lightweight Crewman Communication Umbilical (LCCU) and Crewman Comm Control Head (CCCH)
   - Interface between an SIA Channel A or B CCU disconnect and a comm carrier or lightweight headset assembly.
   - Microphone, earphone, and caution and warning tone lines.
   - Earphone line volume control mounted on a separate control head which could be disconnected.
   - No Bio-Med lines.
   - LCCU could be connected in series for additional length.
   - Transmit and intercom function switch on control head.
   - Length - 208.7 inches.

2.10.1.3 Audio Subsystem Verification Testing

Extensive audio subsystem development testing was conducted prior to finalizing the design of the subsystem configuration. The tests included the following:

- Breadboard design evaluation.
- Black box engineering prototype testing.
- CSM/SWS component interface testing.
- Audio subsystem to caution and warning subsystem interface testing.
- Crew participation of audio subsystem operation including emergency voice configuration.

These series of tests provided MDAC-E with the necessary information required to design and develop a workable audio subsystem which would interface with existing audio components located external to the AM and within the orbital assembly cluster.

A comprehensive acceptance test program was accomplished encompassing piece parts, component level and integrated systems levels. Acceptance tests on the piece parts and unit black boxes were performed using pre-installation acceptance (PIA) or acceptance test procedures (ATP) as noted. These tests included the following equipment:

- Printed circuit boards.
- Speaker.
- Microphone.
- Speaker intercom (ATP).
- Audio load compensator (ATP).
- Crewman communications umbilical.
- Lightweight crewman communications umbilical.
- Control head.

A. The significant anomalies experienced during MDAC-E component testing are delineated in the following paragraphs. Equipment not itemized below had no significant anomalies.

(1) Printed Circuit Board Modules - A total of 280 PC board modules were built and successfully tested. The primary problem experienced during testing was either no output or low output after encapsulation. Performance prior to encapsulation was acceptable. Failure analysis determined that the fault was caused by electrostatic charges developed during handling and encapsulation destroying an integrated circuit. Incorporation of a process specification change which delineated precautionary handling, fabrication and packaging procedures resolved the problem. These PC board modules were primarily used in the speaker intercom assemblies and audio load compensators.

(2) Speaker - A total of 85 speakers were tested. The first units received were returned to the vendor for correction of quality problems (e.g., bad solder, lack of epoxy, improper packaging, and insufficient cleanliness). Subsequent units were all acceptable.

(3) Microphone - A total of 64 microphones were tested and were acceptable with the exception of four units returned to the vendor for rework. Two of these units were contaminated with lint from cleaning swabs, one had intermittent leads, and the other exhibited poor frequency response.

(4) Speaker Intercom - A total of 53 units were built and successfully tested. Resolution of the discrepancies uncovered during testing were expedited to allow for continued production. Two speakers which developed open circuits during SIA burn-in were found to have discolored speaker wiring. This was caused by overheated wiring traced to an incorrect vendor soldering iron size (750°F, S/B 600°F max). The rotary switches used in speaker intercoms exhibited intermittent open circuits. Failure analysis indicated that the waterproofing material had contaminated the internal contacts causing this condition. After the manufacturing process was corrected the switch dash number was changed and serial numbers controlled to preclude the possibility of installing contaminated switches.

(5) Audio Load Compensator - Several failures (oscillation during high temperature test) that occurred during early ATP testing resulted in a more comprehensive investigation of the headset line amplifier output circuit. The problem was traced to a transistor which failed to meet specifications. Thermal runaway occurred in a random sample of the transistors selected for individual testing at one fourth of the rated 800 MW of power. Selecting a different vendor to supply the same part number transistor corrected this problem.

B. During system level tests in St. Louis (Figure 2.10-2), excessive feedback was present when any AM/MDA speaker intercom assembly call switch was placed in the call position. The "call" inputs to all three SIA's were internally adjusted 8 dB lower than ATP values. Feedback was greatly reduced by this technique and was eliminated when a voice signal was applied to each SIA. Final acceptance of the above procedure was delayed until a call test could be performed at 5 psi (altitude

chamber test). At 5 psia the crew exercised the call circuits on the adjusted SIA's and feedback was not present with satisfactory communications being established. The required documentation was changed and all SIA's were adjusted to the new call input levels.

C. During system level tests at KSC (Figure 2.10-3), significant problems resulting from the audio subsystem tests were as follows:

(1) During the CSM/AM/MDA electrical interface docking test, excessive feedback was observed. The volume controls on SIA's at Panels 102, 116, and 131 along with Panel 98 in the CM were adjusted for less volume, eliminating the feedback. As the Panel 116 SIA volume control was adjusted in the opposite direction during transmission from Panel 131, the feedback returned, proving the excess feedback was external to the SIA's. A retest with proper volume control settings was satisfactory.

(2) The rotary switches on 2 SIA's were found to be misaligned after much usage at KSC due to improper installation techniques. Twelve SIA's were removed from the SWS and returned to MDAC-E for modification of the rotary switch installation.

2.10.1.4 Audio Subsystem Mission Performance

A. SL-1/2 Mission - The Skylab audio subsystem was activated on DOY 146 at approximately 17:32 GMT and deactivated on DOY 173 at approximately 05:30 GMT. The audio subsystem provided satisfactory intercommunications for the SL-2 crew and communications between the crew and the ground. The crew utilized the thirteen speaker intercom assemblies located throughout the AM, MDA and OWS to great advantage as direct voice communication was possible only for short distances due to the 5 PSIA atmosphere. Delayed time voice was of excellent signal-to-noise ratio and voice quality, as determined by reviewing tape recordings made during data/voice dumps over the St. Louis STU/STDN tracking station. Communications during the two SL-2 EVA periods was also highly satisfactory.

Audio feedback was observed periodically during crew utilization of the speaker intercom assemblies. This condition was attributed to the crew having too many SIA's operational, the SIA speaker volume

controls adjusted too high, and the crew voice modulating the SIA at distances greater than 12 inches. This feedback condition did not appear to bother the crew as they appeared to have made no specific attempt to control the SIA configuration, nor had they complained about the feedback. The greatest problem with the feedback condition appeared to be a slight annoyance to the ground station listeners.

The following comments relating to the SWS audio subsystem performance were provided by the SL-2 crew during the post mission debriefing.

- The SIA volume level and quality were adequate.
- Initial CSM volume control settings were adequate and did not require readjustment.
- The quantity and placement of SIA's were satisfactory. The SIA located at the OWS dome was not utilized too often, however it was required on several occasions. The SIA located near the bicycle in the experiment area was not in the best location. A better location may have been above the Experiment Support System. The SIA location by the M131 chair was not required.
- The type and number of functions on the SIA's were adequate. However, the ICOM/PTT switch and the voice RECORD switch which were located in line with each other should have been different types or installed perpendicular to each other providing different toggle axes. Several times the voice RECORD switch was inadvertently depressed instead of the ICOM/XMIT switch.
- The SIA's were utilized approximately 90% of the time. The lightweight headsets were utilized during EREP passes and for S019 operation. The comm carrier headsets were utilized during EVA.
- Microdot and zero G connectors on the SIA's functioned properly. The Microdot connector was more desirable than the zero G type.
- Audio feedback was observed in both the MDA and OWS. SIA 131 was utilized mainly in the MDA. The other two units usually remained in a "sleep" mode. In the OWS the SIA located in the wardroom was utilized most of the time. The SIA located at the Scientific Airlock directly above the wardroom caused considerable feedback when it was left on. Also the SIA's by the M131 chair, the bicycle and the one

in the commander's sleep compartment caused quite a bit of feedback. The SIA in the waste management area required a higher than normal volume setting to cause feedback. There was no feedback between the three SIA's in the sleep compartments.

- Adjustment of the volume control setting on the activated SIA's was not attempted as a means to eliminate audio feedback. The procedure utilized to eliminate the squeal was to position the problem SIA's to the "sleep" position. The call function was not utilized and, as such, it was not known if similar feedback would have occurred in this mode of operation. The crew suggested that a procedure, other than positioning the unused SIA's to the "sleep" setting, be considered for remaining manned missions.

B. SL-3 Mission - Between the time period of SL-2 return and SL-3 launch, MDAC-E investigated the audio feedback problem encountered during the SL-2 mission, to provide a workaround technique to eliminate audio feedback as a problem on future Skylab missions. MDAC-E conducted audio/acoustical testing employing speaker intercom assemblies in the St. Louis STU/STDN, the AM/MDA U-2 and the Huntington Beach-based OWS-2 spacecraft. This testing resulted in the formulation of a procedure to minimize or eliminate audio feedback on the SL-3 and SL-4 missions.

The Skylab Channel A audio subsystem was activated during SL-3 on DOY 209 at approximately 22:40 GMT. The Channel A audio subsystem was utilized exclusively to provide air/ground communications, inter-communications, and delayed time voice through DOY 212. Crew voice transmissions were of satisfactory quality throughout this period. On DOY 212 the Channel B audio circuit was activated for the purpose of providing private recording capability on the AM tape recorders. The tape dumps following this activation resulted in unintelligible delayed time voice reception at the STDN. The crew made a number of satisfactory Channel A delayed time voice tape recordings on DOY 213, thereby eliminating the tape recorder as the source of the problem. The audio system was then reconfigured to provide air/ground and intercommunications on Channel B, and private record (delayed time voice) communications on Channel A. On DOY 221 the crew conducted a troubleshooting procedure on the Channel B audio circuit.

MDAC-E determined that the delayed time voice problem was within the Channel B audio load compensator (ALC) tape recorder amplifier and its associated power supply. This problem, however, did not degrade the ALC microphone and earphone line amplifiers and therefore the ALC continued to provide satisfactory communications.

MDAC-E designed and fabricated a contingency emergency/tape recorder voice adapter cable which, when utilized in conjunction with an LCCU, would provide AM voice tape recordings and/or emergency voice modulation of a telemetry transmitter from the Channel A or Channel B microphone lines in the event of Channel A tape recorder amplifier failure. This concept was verified in the STU/STDN and successfully tested on the Airlock U-2. This cable was included in the SL-4 stowage.

On DOY 229 the crew reported that the SIA located at the OWS -Z SAL developed a mechanical malfunction in the ICOM/XMIT toggle switch. This SIA was successfully replaced with an onboard spare on DOY 230.

During the planning for a possible rescue mission, an adapter cable supplied to MDAC-E by Rockwell International was tested on U-2. This cable provided the capability of interconnecting a radial-docked CSM audio system to the SWS microphone and earphone lines distribution system. In addition, this cable could be utilized to provide air to ground or intercom capabilities from an axial docked CSM in case of a Channel A or B ALC malfunction.

On DOY 265, following the post EVA comm reconfiguration, the crew reported hearing a four-cycle oscillation in the SIA's on Channel B. This oscillation was accompanied by an apparent drop in the Channel B earphone line volume level. Crew troubleshooting appeared to isolate the problem to the Channel B ALC secondary headset line amplifier. At approximately 20:45 GMT on DOY 265 the oscillation disappeared and the earphone line volume level returned to normal. During the period that the problem occurred, the crew reported that they were able to communicate satisfactorily over the Channel B audio circuit by increasing the SIA volume control to compensate for the apparent drop in ALC gain. No

additional equipment was flown up on SL-4 to correct a recurrence of this situation as sufficient workarounds were available to maintain communications. Following deactivation, the crew commented that the same four cycle per second oscillation problem had recurred; however, this time on the CSM comm after CSM/SWS undocking.

On DOY 268 at 13:30 GMT the Skylab audio subsystem was deactivated. During the time period from DOY 209 thru DOY 268 the audio subsystem had provided 1407 hours of satisfactory communications.

C. SL-4 Mission

(1) During the SL-3 technical crew debriefing, the crew stated that acoustical feedback was experienced when utilizing SIA's. The crew attempted to resolve this problem by implementing a procedure which required that all SIA volume controls be adjusted to a 9 o'clock position. This procedure eliminated feedback; however, it also reduced the SIA volume to a level which was unusable. The final solution was to operate the wardroom SIA at a very high volume and position all the other workshop SIA volume controls very low. This configuration appeared to deliver the best results although periodically some SIA's would require temporary volume control readjustment. The crew also stated that this configuration also resulted in uplink voice comm volume levels which were less than satisfactory when the listener was not in close proximity to an SIA.

MDAC-E evaluated this situation at the St. Louis STU/STDN and con-concluded that the feedback problem could be prevented by decreasing the SWS microphone line gain by a factor of 10 to 12 dB and talking within 4 to 6 inches from the SIA microphones. This concept was presented to the crew during the SL-3 I&C debriefing session. This concept was accepted and shortly thereafter requirements were initiated to have MDAC-E fabricate a microphone line load which was adjustable and could be installed on an SIA CCU connector. MDAC-E fabricated, tested, and delivered a variable SIA microphone line load to KSC for SL-4 stowage. This load was adjustable from a maximum load value of 100 ohms to a minimum of 600 ohms. This corresponded to a decrease in SIA output of 10 dB at maximum load setting to 2.7 dB at minimum load setting.

Previous spacecraft testing at St. Louis on U-1 had determined that the audio subsystem sidetone volume level developed during an SWS-initiated transmit function would increase approximately 5 dB above the sidetone volume level developed during an SWS initiated ICOM function, because of an increase in sidetone gain of the CSM audio center during transmit. This problem aggravated the feedback situation as adjustment of the SIA volume controls for a satisfactory sidetone volume level during SWS ICOM functions would result in feedback during SWS-initiated transmit functions. Conversely, satisfactory volume level adjustment during transmit functions would result in low sidetone volume levels during ICOM functions. This variation in sidetone level prompted additional evaluation of feedback prevention which resulted in a requirement to fabricate an anti-feedback network communication assembly which would reduce the SWS microphone line gain and reduce the CSM/SWS earphone line signal level during initiation of SWS transmit functions. This assembly was fabricated by Rockwell International, as the device was to mate a CSM CCU disconnect. The flight assembly was delivered to MDAC-E for compatibility testing with the STU/STDN and final adjustment of the load values. This unit successfully completed a mechanical and electrical compatibility test. The microphone line load was adjusted to reduce the SWS microphone circuit audio signals by a factor of 11 dB and the earphone line load was adjusted to reduce the earphone sidetone level by a factor of 6 dB during SWS initiation of a transmit function. After the adjustment, the unit successfully demonstrated the ability to prevent acoustical feedback when the SIA volume controls were not increased greater than 11 o'clock. In addition, the uplink S-band received voice volume level was improved as the SIA volume controls could be operated higher than before. At the completion of this testing, the unit was delivered to KSC for SL-4 stowage in place of the MDAC-E variable microphone line load.

(2) The Skylab audio subsystem was reactivated on SL-4 on DOY 321 at approximately 17:00 GMT. The subsystem operation after activation was nominal; however, acoustical feedback was occasionally noted during crew transmissions.

On DOY 323 the ground controllers initiated a crew alert to verify the C&W and audio subsystem interface operational status. The warning tone performed as expected; however, an attempt was made to initiate voice communications during the crew alert warning tone presence. This mode of operation resulted in very weak intercom voice transmissions. The mission controllers were advised that voice transmissions during a crew alert would be very weak as previously experienced during KSC testing. Downlink voice transmissions were not affected during this mode. MDAC-E recommended that voice communications not be attempted until after the C&W subsystem master alarm had been reset.

On DOY 328 the crew installed the anti-feedback communication network assembly. The crew reported that the unit was operating satisfactorily and was preventing acoustical feedback as long as the SIA volume controls were kept at a reasonable level.

On DOY 333 the crew reported that the SIA located at station 131 developed a malfunction. Crew troubleshooting determined the problem to be isolated within the microphone channel circuitry as the unit would receive but would not initiate voice communications. The crew successfully replaced the defective unit on DOY 334 with an onboard spare.

On DOY 019, the crew reported a 6 Hz noise on the Channel B earphone line audio. This noise was not present on real-time downlink nor on Channel A. Troubleshooting revealed that the CSM audio configuration had no effect on the problem; however, opening the Audio Buffer Amps #1 Circuit Breaker caused the noise to cease and it would gradually build up when the breaker was closed. These symptoms

indicated that the problem originated in the Channel B ALC secondary earphone line amplifier. Analysis in the STU/STDN of a VTR dump tape containing both Channel A and Channel B audio confirmed that diagnosis and also that the Channel B audio was about 6 dB below Channel A and remained at the same level whether or not the Audio Buffer Amps #1 breaker was closed. As a result of this problem, the crew elected to install the emergency/tape recorder voice cable provided as SL-4 stowage. This cable replaced a tape recorder "Y" cable and was connected between a tape recorder and an SIA CCU connector via a lightweight CCU, and provided audio input to the tape recorder directly from the SWS microphone line. The cable was installed on DOY 30 on tape recorder #1, but subsequent voice dumps were of poor quality because the audio level was too low, and the cable was removed on DOY 32. The reduction in overall gain to the tape recorder when using the cable required a higher audio level from crew voices than for the normal configuration. It is believed that the crew did not provide a high enough voice level, although they were informed of this requirement.

2.10.1.5 Conclusions and Recommendations

A. Conclusions - The Skylab audio subsystem successfully provided intercommunications, air to ground communications and voice tape recording functions throughout the SL-2, 3 and 4 missions. There were instances in which the subsystem incurred a definite malfunction. All but one of these malfunctions were corrected or compensated for during flight by inflight replacement of failed components or by reconfiguration of the audio subsystem. The last audio system problem, which could not be completely corrected did not significantly degrade performance, and was partially compensated for by workaround procedures.

An additional problem which occurred but had been preflight identified as a potential problem was acoustical feedback occurring during operation from certain SIA locations. This feedback did not hinder communications; however, it did cause minor aggravation to the crews. This feedback problem was alleviated with the use of the anti-feedback communication network which was fabricated for the SL-4 mission.

B. Recommendations - Future manned space programs involving the use of loud speaker transducers in a voice intercommunication subsystem must include the necessary design and testing to preclude the possibility of acoustical feedback from occurring during operation in the flight environment. The recommended techniques which could be implemented are as follows:

(1) Limited use of loud speakers and/or compartment acoustical isolation between communication stations.

(2) Battery operated wireless microphones which include low sensitivity microphones and are retained on the crewman person and held in close proximity to the voice source ($\sim$1 to 4 inches). These devices should include individual transmission frequencies for each crewman.

Hearing aids should be considered for crewmen utilization during habitation of low pressure environments. These devices will compensate for the drop in acoustical efficiency of the atmospheric medium and in effect will allow loud speaker volumes to be reduced to a lower level and enable some voice conversations to take place without the aid of intercom systems.

2.10.2 Data Transmission and Antenna Subsystem

2.10.2.1 Data Transmission and Antenna Subsystem Design Requirements

A. Data Transmission Subsystem - The data transmission subsystem was required to provide RF transmission capability to the STDN during pre-launch, launch, and orbital phases of the Skylab mission. The transmission system modulation was to be comprised of real time PCM and delayed time PCM.

B. Antenna Subsystem - An antenna subsystem was required to provide for reception and transmission of RF signals to and from the STDN.

2.10.2.2 Data Transmission and Antenna Subsystem Description

The following paragraphs present the evolution of design changes to the data transmission and antenna subsystem, equipment characteristics, and configuration of the final flight subsystem utilized on Skylab 1. The flight subsystem was configured as shown in Figure 2.10-5.

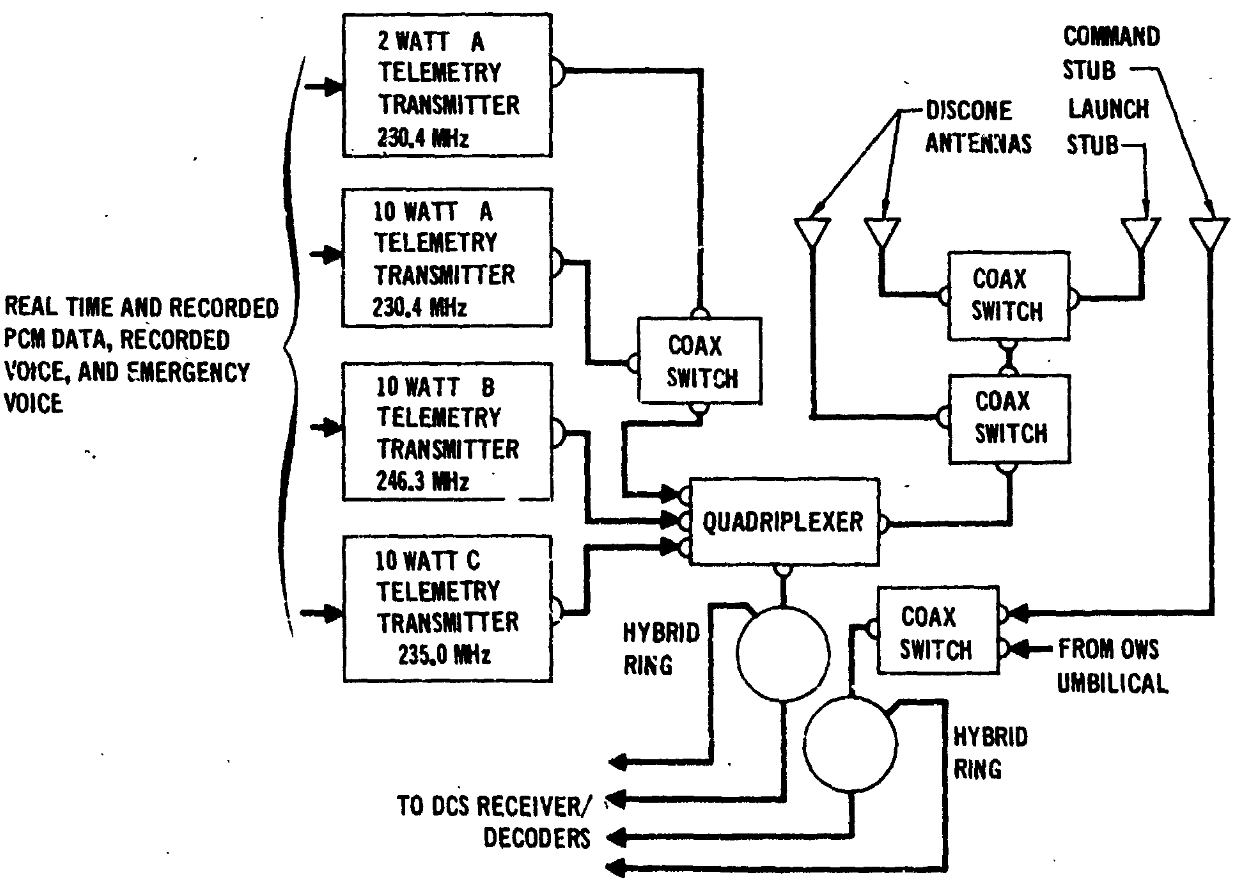


FIGURE 2.10-5 AIRLOCK DATA TRANSMISSION AND ANTENNA SYSTEM

A. Data Transmission Subsystem - The data transmission subsystem required two major changes to arrive at the final flight configuration. These changes were required to comply with program requirements that expanded as the needs of the Skylab vehicle were better identified.

(1) The initial configuration was comprised of two (2) 2-watt Gemini type frequency-modulated telemetry transmitters. One transmitter operating on 230.4 MHz would provide real time PCM transmissions. The second transmitter operated on a frequency of 246.3 MHz and provided delayed time PCM transmissions. Modulation switching controlled manually or by the DCS would permit either transmitter to be selected for each type of data transmission.

(2) The first major change implemented to the data transmission system added a third telemetry transmitter to enable recorded voice data to be dumped to the STDN simultaneously with the transmission of real time PCM and delayed time PCM. The incorporation of a third telemetry transmitter occurred concurrently with the deletion of the voice subsystem VHF transceivers thereby making available a quadriplexer channel. The initial concept for the third transmitter used a retuned Gemini 2-watt unit; however, tradeoffs between transmitter availability versus ground station signal-to-noise ratio requirements justified incorporation of a 10-watt transmitter.

(3) The second major change to the data transmission subsystem configuration resulted from the data modulation bandwidth requirements being expanded to a point where 2-watt transmitters would not produce a satisfactory signal to noise ratio at the STDN. A MDAC-E study was conducted which determined that 10-watt transmitters would provide the needed transmitted power. The units chosen were existing design and qualified frequency modulated telemetry transmitters previously flown on the Apollo program block I boosters.

(4) The final flight configuration utilized three (3) 10-watt transmitters and one (1) 2-watt transmitter. The 2-watt transmitter was required to provide real time telemetry transmissions during the launch phase of the mission as the 10-watt units would cause

corona within the antenna subsystem quadriplexer when the vehicle trajectory passed through the altitude regions conducive to corona. After vehicle orbital insertion, the launch 2-watt transmitter was to be deactivated and the three 10-watt units activated. Modulation switching, controlled either manually or by ground command, permitted any of the data sources to be transmitted and provided the capability to transmit three data sources simultaneously. The 10-watt transmitters that were flown were versions of the units that were initially procured and modified to utilize high reliability screened parts and incorporate a VHF isolator.

Telemetry Transmitter Characteristics:

- Telemetry Transmitter 2-Watt - The Airlock "A" 2-watt transmitter was frequency modulated and operated on a center frequency of 230.4 MHz. It was utilized to provide real time transmission to the STDN during the launch phase of SL-1, serving as a backup transmitter during the orbital phase of the mission. The transmitter output power was attenuated by a 2.8 dB lossy coaxial cable to prevent corona from occurring within the quadriplexer during ascent. The transmitter had the following characteristics:

Input Power	20.5 watts maximum
Output Power	2.0 watts minimum, 2.6 watts nominal
Frequency Stability	$\pm$0.01% of assigned after 30 second warmup
Modulation Sensitivity	1V $\pm$1 dB peak for 100 KHz peak deviation
Location	Electronics Module No. 2

- Telemetry Transmitter 10-Watt - The Airlock 10-watt transmitters were frequency modulated and designated as "A", "B", and "C". The "A" center frequency was 230.4 MHz, the "B" center frequency was 246.3 MHz and the "C" center frequency was 235.0 MHz. Transmitters input modulation switching was controlled either manually or by ground command, and permitted transmission of either real time or delayed time data and voice to the STDN. The transmitters had the following characteristics:

Input Power	80 watts maximum
Output Power	10 watts minimum, 15 watts maximum
Frequency Stability	±0.01% of assigned after 30 second warmup
Modulation Sensitivity	1V ±1 dB peak for 100 KHz peak deviation
Location	Electronics Module No. 2

B. Antenna Subsystem - The antenna subsystem required three major changes to arrive at the final flight configuration. These changes were required to comply with program requirements that expanded as the needs of the Skylab vehicle were better identified.

(1) The initial antenna subsystem configuration was comprised of two Gemini VHF whip antennas, one Gemini UHF nose stub antenna, one Gemini quadriplexer modified to accommodate a new transmitter frequency, one Gemini diplexer retuned to accommodate a new voice receiver frequency, and one Gemini RF coaxial switch. The antenna subsystem provided the capability for reception of 450 MHz command transmissions, reception of 259.7 MHz voice transmissions, and transmission of 296.8 MHz voice and 230.4, 246.3 MHz telemetry. The modified Gemini quadriplexer permitted transmission and/or reception of four separate RF signals from either the launch/orbital or orbital antenna. The retuned Gemini diplexer permitted the reception of two separate RF signals from the receive antenna. The coaxial switch provided a means to permit optimum selection between the launch/orbital and orbital antennas.

(2) The first major change implemented to the antenna subsystem added two discone antennas mounted on 30 foot extendible booms, a parasitic antenna subsystem consisting of a Gemini UHF nose stub and a modified Gemini VHF descent antenna, a second coaxial switch and two DCS hybrid rings. The discone antennas were needed to provide adequate antenna coverage as the original whip antenna coverage was degraded by the incorporation of solar arrays. After orbital insertion, the discone antennas were extended on booms to minimize shadowing effects from the solar arrays. The original coaxial switch was used to select the optimum of the two discones. The original whip antennas were to be located on the aft SLA panels. One of the whip antennas was to provide telemetry transmission and command reception during launch, and backup for the discones during orbital phases; the second whip antenna was to provide command reception during launch, and reception of command and voice during orbital phases. The parasitic antennas were to consist of a modified Gemini UHF nose stub antenna located on the external portion of the AM structural transition section, and a modified Gemini VHF descent antenna located in the EVA lock compartment. This antenna configuration would enable pre-EVA checkout of the crewmen portable life support system (PLSS) RF communications. Concurrent with this revision to the antenna subsystem, an additional DCS receiver/decoder was added to provide redundancy. This DCS addition required a method to couple the quadriplexer command channel output and the diplexer command channel output to the four DCS receivers. Two coaxial hybrid rings were incorporated into the antenna system to satisfy the DCS receivers antenna coupling requirements. The addition of the second coaxial switch enabled the quadriplexer antenna port to be selected between the discone antennas or the launch whip.

(3) The deletion of the AM voice communication subsystem resulted in the second major antenna system change, deleting the diplexer and the parasitic antennas. The command/duplex receive antenna, reidentified as the command whip, was retained and utilized for only command receptions.

(4) The final flight configuration changes required the addition of two coaxial switches and replacement of the UHF whip antennas with modified Gemini UHF nose stubs. The addition of one of the coaxial switches resulted from a requirement to enable selection between the 2-watt and 10-watt 230.4 MHz transmitters. The other was needed to enable hardline reception to the DCS receivers during ground checkout. The replacement of the antennas was necessary as the whip antennas could not comply with the redefined structural vibration requirements.

The antenna subsystem configuration utilized during flight is shown in Figure 2.10-5. Component characteristics were as follows:

- Quadriplexer - The quadriplexer was a passive multicoupler which combined four frequencies into one antenna system. Three channels provided coupling of 230.4, 235.0 and 246.3 MHz transmitter signals and the remaining channel provided reception of 450.0 MHz command signals. The quadriplexer was located on the Airlock Electronics Module No. 2.
- RF Coaxial Switches - The Airlock utilized four RF coaxial switches, three of which were controlled either by DCS command or manually, and the fourth by ground support equipment. Two switches were utilized for flight antenna selection between the two discones and the stub antenna. The third was used to select between the "A" 2-watt and "A" 10-watt transmitter. A fourth switch, located adjacent to Electronics Module No. 6, controlled via the OWS ground umbilical, was utilized to select between ground hardline and the command stub antenna inputs to the DCS receivers during ground testing. Each coaxial switch consumed 18 watts maximum while switching.

- Launch Stub - The launch stub antenna was mounted on the FAS under a protective fairing and was utilized for telemetry transmission and command reception during the vehicle launch phase of the mission. During the orbital phase of the mission the antenna served as a backup to the discone antenna system for telemetry transmissions and command reception. During launch, the antenna, a 1/4 wavelength monopole radiator, provided a gain of 0 dB or better when referenced to an isotropic radiator over 44% of a sphere for telemetry transmissions, and a gain of -14 dB or better over 83% of a sphere for command reception. During the orbital phase of the mission, it provided a gain of -5 dB or better over 58% of a sphere for telemetry transmissions.
- Command Stub - The command stub antenna was located on the Fixed Airlock Shroud under a protective fairing, and was utilized for command reception during the vehicle launch and orbital phases of the mission. The antenna, also a 1/4 wavelength monopole radiator, provided a gain of -14 dB or better, when referenced to an isotropic radiator over 83% of a sphere, during launch and -14 dB gain or better over 88% of a sphere in orbit.
- Discone Antennas - Two discone antennas were installed on antenna booms erected after payload shroud jettison, and were configured so that radiation coverage of one antenna was 90° (degrees) with respect to the other. Each was a bi-conical radiator consisting of a 10-inch diameter disc mounted and insulated from the apex of a cone assembly. The cone was approximately 1/4 wavelength at its widest point and approximately 1/4 wavelength long, referenced to its lowest operating frequency of 230 MHz. These antennas were the radiating elements for telemetry

transmission and command reception during the orbital phase. The STDN operators could select the proper discone antenna by ground command to optimize coverage. The discone antenna provided a gain of -5 dB or better when referenced to an isotropic radiator over 70% of a sphere for the telemetry transmission frequencies and -14 dB gain or better over 96% of a sphere for the command reception frequency. STDN selection of the optimum discone antenna via the command system resulted in an antenna gain of -5 dB or better over 85% of a sphere for the telemetry frequencies and -14 dB or better over 97% of a sphere for the command reception frequency.

- DCS Hybrid Ring - The AM hybrid coaxial ring assembly permitted two DCS receivers to be operated from one antenna, and consisted of a 1 1/2 wavelength section of coaxial cable connected in a loop configuration. One half (3/4 wavelength) of the loop was tapped in four places with coaxial tee connectors spaced 1/4 wavelength apart. One port was connected to the antenna. The two ports that were one half wavelength apart were connected to the receivers. The remaining port was terminated with a 50 ohm load. This device had an insertion loss of 3 dB from the antenna to any one receiver and maintained an isolation of at least 20 dB between the receivers. The antenna subsystem utilized two hybrid ring assemblies to enable the 4 DCS receivers to be connected to two antennas.

2.10.2.3 Data Transmission and Antenna Subsystem Test Results

The data transmitters, coaxial switches, and quadriplexer followed the normal test flow: vendor ATP, bench level PIA, electronics module, then the vehicle systems level at both MDAC-E and KSC. Refer to Figure 2.10-2 and 2.10-3 for MDAC-E and KSC vehicle-systems-level test flow. Detailed component and module level tests were emphasized on the antennas as the reflective environment was not conducive to RF free-space tests. The discone boom rotary joints would not withstand one "G" vehicle deployment; therefore, discone antenna and boom coaxial segments were VSWR monitored during testing performed on a specially designed fixture which would support boom deployment in a one-g environment. VSWR tests of the discone antenna assemblies were made in a nearly reflection-free environment on a timber-tower. Satisfactory testing of the launch stub and command stub was accomplished on the FAS module. RF compatibility tests using flight antenna prototypes were successfully performed during simulated flight tests. Coaxial cable VSWR and insertion loss measurements were made at module and total vehicle levels.

A. Component Testing - The significant problems experienced during MDAC-E component testing are discussed below. Those components not discussed experienced no significant problems at the component level.

(1) Stub Antenna - During acceptance tests the 450 MHz VSWR of two antennas did not meet the "not-more-than 5:1" specification. The cause was traced to improper antenna assembly and was corrected.

(2) 10-Watt TM Transmitter - During PIA of S/N 100, a random failure of one transistor and two resistors caused an increase in input current. The faulty components were replaced.

(3) 2-Watt TM Transmitter - Random failures experienced during PIA testing included: S/N 20 RF power loss due to a capacitor failure, and S/N 21 RF power loss due to capacitor metal contamination, resulting in a short. Replacement of failed components resolved the problems.

(4) Coaxial Switch - During post requalification vibration test, port 2 of S/N 111 coaxial switch indicated an out of specification insertion loss. Failure analysis showed burned

RF switching contacts presumably overstressed at MDAC-E during PIA Power Altitude tests. The power altitude test was deleted from the PIA procedure. All flight switches incorporated new RF switching contacts.

B. System Testing - The evaluation and verification of subsystem performance was accomplished during Electronics Module No. 2 test, antenna and coaxial tests and six major vehicle level tests as shown by Figure 2.10-2. Significant antenna and data transmission subsystem problems were:

(1) During Electronics Module 2 tests, it was discovered that defective coaxial cable connectors were being utilized during the coaxial cable assembly. Rework of Airlock U-1 cable assemblies and future built assemblies was accomplished using X-rays to determine acceptability of coaxial cable connector fabrication.

(2) During systems validation test, the two-watt telemetry transmitter, S/N 21 output RF power, when measured on the antenna side of the quadriplexer, was 1.74 watts (should be not-less-than 2 watts). The fault was isolated to the transmitter. Failure analysis revealed a capacitor had failed due to a minute metal flake which created a resistance short causing the transmitter to be mistuned.

(3) During systems assurance test, the 10-watt transmitters "A" and "C" PCM peak deviation measured 160 KHz and 189 KHz respectively, (should be 87.5 $^{+35}_{-16}$ KHz). Excessive noise was found on transmitters "A" and "C" due to a "ringing" between the transmitter voltage regulator and the power input in-line filters. This resulted in oscillations that caused the voltage regulator to drop in and out of regulation with subsequent frequency modulation of the carrier. Since the new transmitters had internal filters installed, the separate power input filters were removed and flight jumper cables were installed.

(4) During altitude chamber tests, corona of the quadriplexer occurred after an eleven minute period at 150,000 feet while using the two-watt transmitter. Laboratory tests determined that corona in

the quadriplexer was also a function of VSWR and phase angle. The cable between the two-watt transmitter and quadriplexer was replaced with a longer cable to increase the insertion loss from 1.8 to 2.8 dB to circumvent the possibility of corona during the launch phase of the mission.

C. Launch Site Tests at KSC - Figure 2.10-3 shows the KSC test flow that was successfully accomplished to satisfy the test requirements. There were no significant data transmission or antenna subsystem problems during KSC tests. However, retests of replacement equipment due to problems encountered during ATP or PIA were as follows:

(1) During AM/MDA/OWS end-to-end Electrical Test the 2-watt transmitter was retested after replacement with a unit that incorporated a modification to resolder the tuning slugs.

(2) During SWS Electrical and Mechanical Closeout, all four coaxial switches were retested after replacement with units having new RF switching contacts installed.

2.10.2.4 Data Transmission and Antenna Subsystem Mission Results

A. Data Transmission Subsystem Mission Results

(1) SL-1/2 Mission Results - From launch on DOY 134 at 17:30 GMT to 17:52 GMT, the 230.4 MHz "A" 2-watt transmitter provided transmission of real time telemetry data to the STDN via the launch stub antenna. At 17:52 GMT the real time telemetry transmissions were reconfigured to the "A" 10-watt transmitter operating into the discone antenna system which had been deployed at 17:47 GMT. The "A" 10-watt telemetry transmitter continued to provide real time telemetry and transmitters "B" and "C" were utilized periodically as planned to provide transmissions of delayed time data, experiment data and delayed time voice recordings.

During DOY 134 operations, the STDN reported that the 235.0 MHz "C" transmitter was experiencing occasional dropouts. These dropouts disappeared after the fifth revolution. The problem was speculated as being that the quadriplexer had retained some

residual atmosphere within the 235.0 MHz cavity and resulted in intermittent corona until the quadriplexer venting was complete.

On DOY 158 the STDN reported a loss of signal from the "A" 10-watt transmitter. This loss of signal coincided with the spacecraft atmospheric venting process during EVA preparation. This problem was speculated to have been corona occurring within the quadriplexer. The "A" 2-watt transmitter was activated and restored telemetry data. Approximately 6 hours later the "A" 10-watt transmitter was reactivated and provided real time telemetry transmissions until DOY 163.

During DOY 163 the "A" 10-watt transmitter receiver signal strength indicated a decrease of approximately 12 to 14 dB, in comparison with transmitter "B" and "C" received signal strengths and with transmitter "A" received signal strength of previous days. This decrease was observed over the Hawaii tracking station pass at 163:19:14 GMT through 163:19:20. During this period of time, the "A" 10-watt transmitter received signal varied between -120 dBm to -106 dBm. For the same time period, the "B" transmitter received signal strength varied between -102 dBm to -93 dBm. At 163:19:20 GMT the "A" 2-watt transmitter was activated. The received signal throughout the 2-watt activation period varied between -114 dBm to -101 dBm. At 163:19:45 GMT over the Vanguard tracking station the "A" 10-watt and the "A" 2-watt transmitters were each activated for 1 minute and 15 seconds. The received signal strength indicated that the 2-watt carrier was approximately 3 dB greater than the 10-watt carrier. During the remainder of DOY 163 and periodically throughout DOY 164, the mission controllers continued to cycle between the "A" 2-watt and the "A" 10-watt transmitters. Each of these tests indicated that the 2-watt transmitter was providing approximately 2-3 dB greater received signal at the ground stations. During the remainder of DOY 163 and through DOY 165 the "B"

transmitter had been time shared between real time and delayed time data. On DOY 164, MDAC-E reviewed the St. Louis STU/STDN Rev 428 and 429 data pertaining to transmitter case temperatures, AM bus currents and received signal levels. Evaluation of this data revealed that the "A" 10-watt transmitter case temperature was significantly cooler than the other operational transmitters, and that the AM bus current indicated no change, or a decrease in current when the 10-watt transmitter was selected in place of the 2-watt unit. In addition, the "A" 10-watt case temperature measurements prior to DOY 163 indicated a higher operating temperature. These facts coupled with the decrease in received signal indicated that the "A" 10-watt transmitter RF output power had degraded significantly.

MDAC-E recommended a transmitter reconfiguration to operate the "B" transmitter for real time telemetry until a tape dump utilizing that frequency was required. At that time the real time telemetry would be temporarily configured to the "A" 2-watt transmitter. This recommendation was implemented and continued to be utilized through this period.

(2) SL-3 Mission Results - The "A" 2-watt, and "B" and "C" 10-watt transmitters all continued to operate nominally throughout this period. From DOY 173 through 245, the transmitter configuration was maintained the same as the latter portion of the SL-2 mission. From DOY 246 through the end of the mission, the "B" transmitter was utilized exclusively for transmission of real time telemetry and the "A" 2-watt transmitter was configured for transmission of delayed time voice. Transmitter "C" was utilized only for transmission of delayed time data.

(3) SL-4 Mission Results - The data transmission subsystem performed satisfactorily throughout the SL-4 Mission, except for the occasions discussed below. The transmitters were configured in the same manner as in the latter portion of the SL-3 mission.

On two occasions, on DOY 335 and on DOY 353 transmitter "C" failed to respond to DCS commands to power it. These problems each occurred over a different tracking station and on each occasion the problem disappeared when transmission was attempted over the next tracking station. A review of telemetry for both occasions revealed that the proper DCS commands were received. (On one of the occasions, attempt to power the transmitter was made unsuccessfully via two different DCS commands). Review of bus current and transmitter temperature indications could not isolate the source of the problem. Its cause was speculated to be either temporary contamination of a relay contact through which transmitter "C" power was routed, or an intermittent malfunction internal to the transmitter.

On DOY 17, no signal was received from Transmitter B at AOS at Carnarvon. Real-time telemetry was switched to transmitter C which provided a signal for about 10 seconds. Transmitter B was reselected and it operated for about 1.5 minutes before again dropping off. At AOS at Goldstone, the next station, no signal was received from Transmitter B and the A-2-watt transmitter was selected for real-time telemetry and provided adequate signal. Transmitters B and C operated satisfactory over the Vanguard station for a tape dump and the normal configuration was successfully reestablished. No subsequent problems were noted until DOY 20, when a similar sequence of events occurred. It was noted that both of these occurrences were during M509 experiment runs. Examination of cabin pressure histories indicated pressures high enough to cause the AM cabin pressure relief valves to open. Although the flight plan called for these valves to manually be closed during M509 runs, the crew stated that the one at panel 391 (aft compartment)

had been left open. It is believed that during both incidents, cabin pressure vented under the thermal curtain causing a pressure sufficient for corona in the quadriplexer to be initiated and maintained with a 10-watt signal.

B. Antenna Subsystem Mission Results

(1) SL-1/2 Mission Results - The antenna subsystem and coaxial switches performed satisfactorily throughout this phase of the mission (DOY 134 thru 173). The Launch stub antenna successfully provided real-time telemetry transmission from launch through orbital insertion. At orbital insertion on DOY 134 at 17:46 GMT the discone antenna booms were successfully developed. After deployment the discone antennas were utilized almost exclusively for telemetry transmissions. Selections between discone 1 and discone 2 were made approximately 1720 times via the command system to optimize antenna coverage. The command system antenna coverage was provided by the launch stub and command stub from launch through orbital insertion. After insertion the command system antenna coverage was reconfigured to the discone antenna system and the command stub.

The quadriplexer performed satisfactorily throughout this phase of the mission except during the EVA operations on DOY 158. On that day, as discussed previously, it was suspected that corona occurred in the quadriplexer, caused by the EVA venting process.

(2) SL-3 Mission Results - The antenna system and quadriplexer performed satisfactorily throughout this phase of the mission (DOY 173 thru 268). The discone antenna system was utilized almost exclusively to provide telemetry transmissions and in conjunction with the command stub to provide command system antenna coverage. Selections between discone 1 and discone 2 were made approximately 3000 times to optimize antenna coverage. The launch/orbit antenna and discone antenna coax switches operated nominally throughout this period.

On DOY 176 instrumentation parameter K374 which monitors the 2-watt/10-watt transmitter coax switch activation ceased indicating the change from the 2-watt to the 10-watt transmitter. A review of data received at the St. Louis STU/STDN facility revealed that the coax switch was successfully switching between the transmitters and only the indication had failed.

(3) SL-4 Mission Results - The performance of all portions of the antenna subsystem was considered completely successful during the 137-day SL-4 mission, except for the two occasions noted above on DOY 17 and 20, when the quadriplexer is believed to have experienced corona. The discone antennas were again used for telemetry transmission and command reception (with the command stub) except for rare occasions when the launch stub antenna was selected. Optimum antenna coverage was maintained by selecting between discones 1 and 2 approximately 6000 times.

2.10.2.5 <u>Conclusions and Recommendations</u>

A. Data Transmission Subsystem

(1) Conclusions - The data transmission subsystem successfully provided real time PCM, delayed time PCM, and recorded voice transmissions throughout the period from SL-1 launch to SL-4 deactivation. The "A" 2-watt transmitter provided real time telemetry transmissions from prelaunch through orbital insertion. The "A" 10-watt, "B" and "C" transmitters provided real time PCM, delayed PCM and recorded voice transmissions successfully throughout the Skylab orbital missions with the exception that the "A" 10-watt transmitter developed a malfunction after 29 days of operation. The loss of the "A" 10-watt transmitter did not reduce the amount of data transmission capability as the "A" 2-watt transmitter was reactivated and provided backup capability.

(2) Recommendations - Future space programs requiring the use of telemetry transmitters should employ systems which will minimize the number of transmitters required to process multiple PCM data. A typical system which could be employed to achieve this goal is as follows:

- Transmitter modulation bandwidths increased by a factor of 10 over the existing Skylab units.
- Modulation capability to enable simultaneous transmission of experiment high bit rate data via an FM main carrier and low bit rate housekeeping data via a PM modulated subcarrier.
- Transmission carrier frequencies higher than the present VHF transmitters to enable utilization of wide modulation bandwidths.
- Additional transmitters to provide redundancy capabilities.

B. Antenna Subsystem

(1) Conclusions - The antenna subsystem successfully provided the necessary spherical antenna coverage which enabled reception and transmission of RF signals to and from the STDN throughout the orbital phases of the mission. Antenna requirements were satisfied during the launch phase of the mission via the launch and command stubs. Antenna requirements during the orbital phase of the mission were satisfied via the discone antenna and command stub with occasional usage of the launch stub. The quadriplexer successfully provided isolation between the transmitters and command receivers and coupling between these units and the selected antenna. The three operational coaxial switches provided satisfactory operation throughout the entire mission. The discone antenna coaxial switch was operated approximately 18,000 times to optimize antenna coverage. The only malfunction that occurred within the antenna subsystem resulted when the 2-watt/10-watt coaxial switch microswitch instrumentation monitor circuitry ceased indicating the change from the "A" 2-watt transmitter to the "A" 10-watt transmitter. This malfunction did not affect the RF switching capability of the device and only the indicator circuitry became inoperative.

(2) Recommendations - Future manned space programs requiring multiple antennas to provide the desired radiation distribution coverage should consider employing equipment which will automatically select the optimum antenna for RF transmissions to the ground. Optimum antenna selection could be achieved using received uplink command carrier signal strength. This type of subsystem would require multiple command receivers continuously monitoring each antenna. The benefits from this type of subsystem could improve RF transmissions to the ground and would minimize antenna select command requirements.

Future programs requiring the use of RF switching capabilities should consider the application of circulator switches to eliminate the coaxial switch mechanical problems encountered during past programs. Circulator switches would enable faster RF switching, requires less switching power, and should increase the reliability as compared to present electro-mechanical devices.

2.10.3 Digital Command, Teleprinter and Time Reference Subsystems

Figure 2.10-6 is a block diagram showing the DCS, Teleprinter and TRS subsystem interface relationship.

2.10.3.1 Digital Command Subsystem (DCS)

A. Design Requirements - The original requirement for the DCS was to provide the STDN with real time ground control of spacecraft switching functions. This requirement was accomplished in conjunction with the antenna subsystem (Reference Section 2.10.2). New requirements were added as the program evolved. Reliability considerations, based on mission length, created the requirement for redundancy in the DCS. A requirement to supply updates to the electronic timer was added to

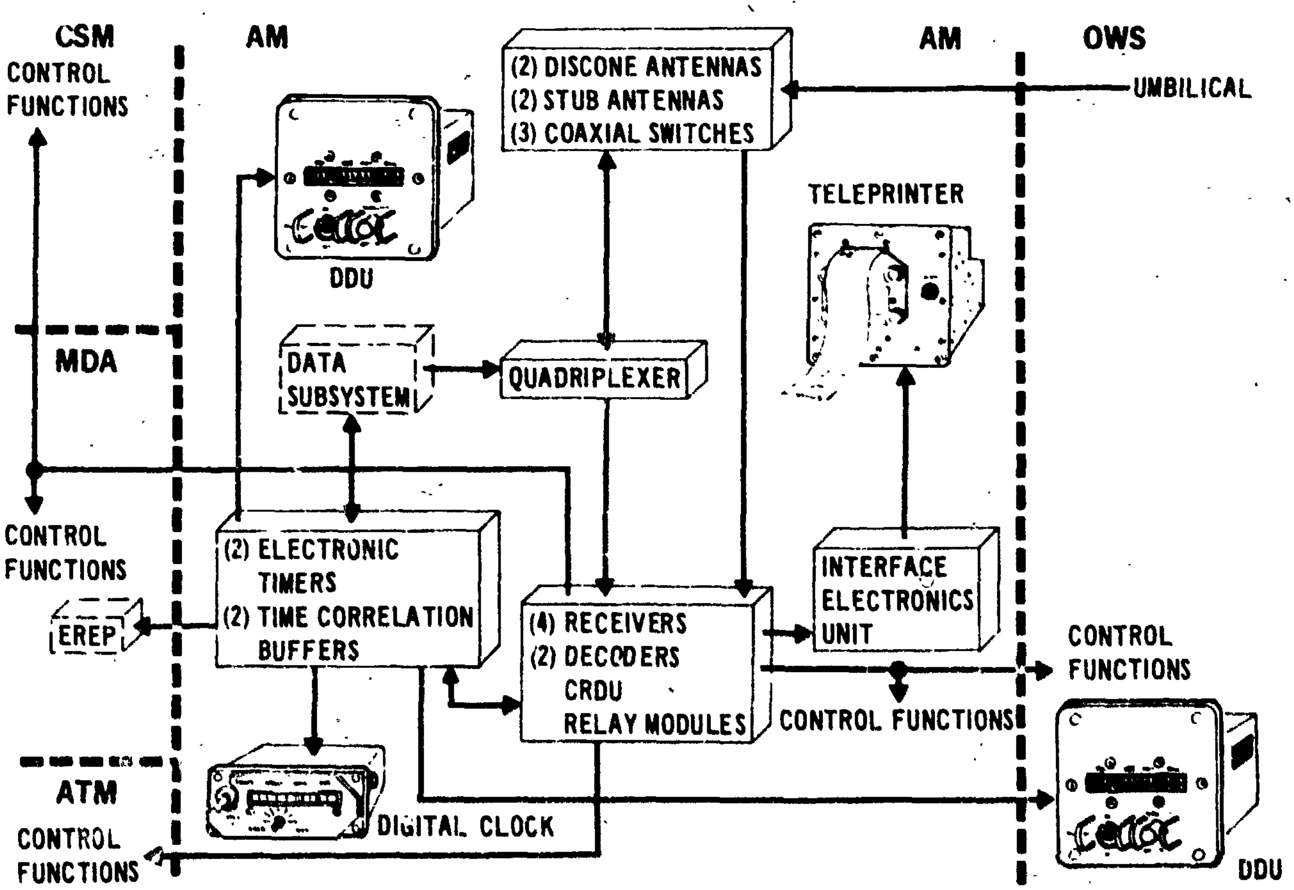


FIGURE 2.10-6 DCS, TELEPRINTER, AND TRS SUBSYSTEM

implement automatic switchover between redundant DCS receiver/decoders, and to provide salvo reset of selected commands. Requirements for additional commands were added throughout the program. With the addition of the teleprinter, the DCS was required to accept and transfer messages to the teleprinter subsystem.

B. Design History, Tradeoffs and Resulting Description of the DCS - The final configuration of the DCS consisted of two receiver/decoder units, four 8-channel relay modules, and a command relay driver unit (CRDU). The original DCS for Airlock consisted of only one NASA Gemini DCS receiver/decoder and two NASA Gemini relay modules, providing a capacity of 32 commands (16 set-reset channels). Early in the program, two additional relay modules were added, giving a capacity of 64 commands. This early system also interfaced with the electronic timer to provide updates to the timer's T_X register. A relay closure from the timer at time T_X provided reset of selected DCS commands.

Reliability considerations resulted in the addition of a second receiver/decoder. A two-vehicle address concept was initiated to maintain individual control over each receiver/decoder; that is, each receiver/decoder was assigned a separate vehicle address. This configuration was chosen to maximize system reliability by providing a fully operational unit even if a failure would occur in the other. This arrangement also provided the capability of independently assessing each system's operational status during flight. The two-address concept was disadvantageous in terms of ground control in that the command formatting program was complicated by having to provide for a second Airlock vehicle address.

Switchover between receiver/decoders was automated by the use of the T_r capability of the electronic timer. An interface was added between the receiver/decoders and the electronic timer to provide an update capability to the T_r register. The "T_r-30 seconds" relay closure output of the timer was connected to relay circuitry which, if the T_r register was allowed to time out, activated the redundant

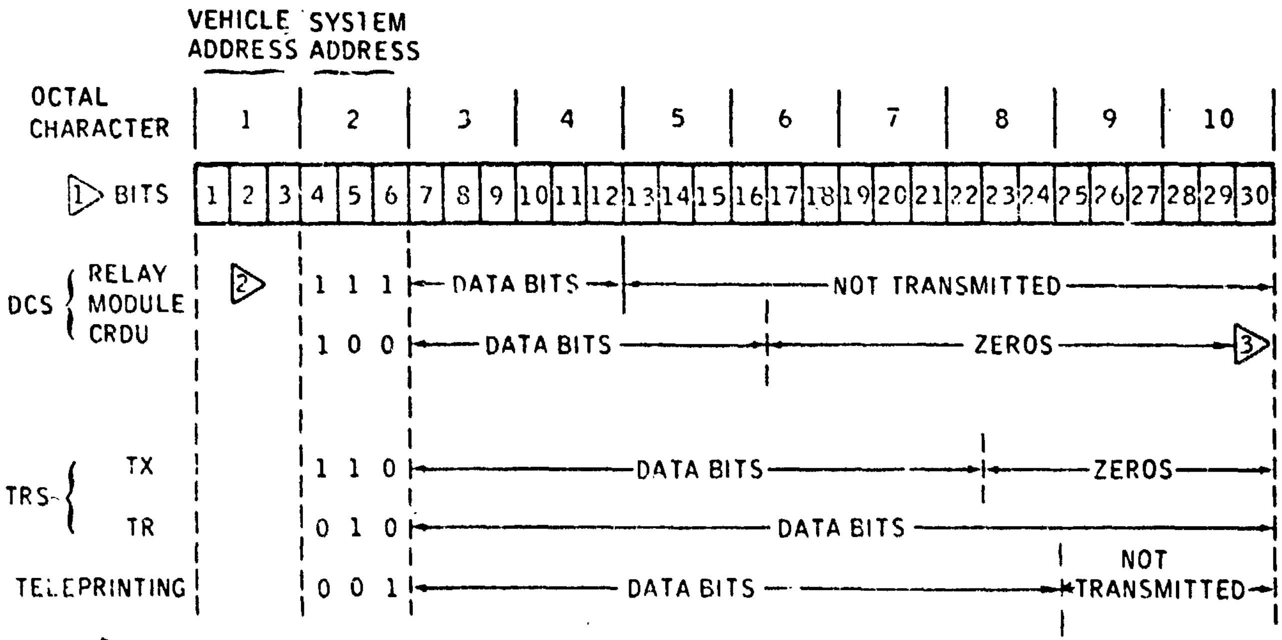
receiver/decoder. The active receiver/decoder would periodically update the T_r register. Failure to do so, because of DCS failure, would automatically activate the redundant receiver/decoder.

Addition of new command requirements on the DCS required expansion of the capacity of the system. A multiplexing arrangement of existing relay module outputs was considered. This concept would have used 16 relays to provide only an additional 9 commands. The sequence of operations would have been constrained with up to three commands required to initiate one function. A far more favorable method of expanding the command capability was through the use of the Gemini receiver/decoder's stored program output which originally provided update capability to the Gemini computer. A new component, the command relay driver unit (CRDU) was added which utilized stored program command messages to provide additional pulse command outputs to drive latching relays. At the expense of additional size, weight, and power, this unit provided the advantages of being able to add a large number of additional commands while using one command message per command, providing a direct telemetry readout of the command processed, and being able to tailor the output drivers to the existing relay circuitry. In addition, the capability to process the stored program commands already existed in the DCS ground station.

The addition of the teleprinter required no modification to the DCS System. A spare system address and output was used to interface with the teleprinter system.

(1) Receiver/Decoder - Each receiver/decoder contained two receivers and a decoder section. Each receiver was connected to a separate antenna and received commands transmitted by the STDN on a phase shift keyed frequency-modulated 450 MHz carrier. Minimum receiver sensitivity was -93 dBm. The demodulated signals from both receivers were linearly summed and sent to the decoder. The decoder, after decoding a command, provided either digital data to the electronic timer, CRDU, or the teleprinter subsystem, or a discrete pulse command to a relay in one of the relay

modules. Each command could be up to 30 bits long and was sent in sub-bit form, with 5 sub-bits per bit. Reference Figure 2.10-7 for command message format. The first 3 bits were the vehicle address, designating which receiver/decoder was to receive the commands; the second 3 bits were the system address, designating the destination of the command (relay modules, CRDU, electronic timer T_r or T_x registers, or teleprinter); the remaining bits were data. Six data bits were required for the relay modules, 24 for the CRDU and electronic timer, and 18 for the teleprinter. A verification or complete message pulse was sent to the Airlock telemetry system after each valid message, indicating that the entire message was correctly received and decoded.



1. EACH BIT WAS COMPOSED OF 5 SUB-BITS. BIT 1 WAS TRANSMITTED FIRST.
2. THE OAM VEHICLE ADDRESS FOR THE PRIMARY AND SECONDARY RCVR/DCDR WAS:
   PRI RCVR/DCDR 010
   SEC RCVR/DCDR 101
3. BIT 30 WAS USED TO MAINTAIN ODD PARITY.

FIGURE 2.10-7 COMMAND CODE FORMAT

The Airlock receiver/decoders were of two designs, electrically and mechanically interchangeable. The original intent was to utilize spare Gemini receiver/decoders. However, an insufficient quantity of Gemini receiver/decoders existed to fulfill requirements for redundant units on both Airlock vehicles and ground spares. Three alternatives for supplying additional units existed: build new units identical to the Gemini units; adapt hardware from another program; or build a hybrid unit interchangeable with the Gemini unit. The first alternative was impractical because parts were no longer available and manufacturing techniques had changed considerably in the time period since the last Gemini unit was built. The second alternative, utilizing an Apollo up-data link (UDL) with a new receiver buffer, appeared attractive because the development risk was thought to be less than for a new design receiver/decoder. However, the hybrid design approach was ultimately chosen, which provided interchangeability between units and allowed usage of the Gemini DCS ground support equipment without modification. This method also did not require a high bit rate digital interface which would have been required with the Apollo UDL approach. The hybrid units were designed using some UDL modules and a new receiver, but Gemini logic design was used where possible. The Gemini and hybrid units, although not identical in physical dimension and internal circuitry, were mechanically and electrically interchangeable.

The hybrid unit was originally intended for use only on the second Airlock vehicle. However, ultimately one of each type was flown on the Skylab I vehicle.

An original Gemini design requirement was for the receiver/decoder to operate as a single unit, and its circuits were designed for that requirement. The incorporation of two receiver/decoders on Airlock, capable of being operated simultaneously, produced one incompatibility in the interface between the receiver/decoders and the relay modules. Commonality between portions of the vehicle address recognition logic and the real-time command logic in the receiver/decoder produced a sneak ground path such that with both units powered, real-time command Channel 1 or 32 was activated every time another set or reset command was sent. Since only 27 out of the 32 relay module channels were required in the final configuration, the vehicle wiring was modified to eliminate the use of these two command channels to resolve this incompatibility. This incompatibility was discovered during simulated flight tests late in the program; therefore, it existed with both the Gemini and hybrid receiver/decoder units.

(2) Relay Modules - The Gemini relay modules were utilized unmodified on the Airlock. Each of the four relay modules contained eight latching relays, each driven by set or reset commands from the receiver/decoders. Thirty real-time command channels were provided, giving a total of 60 set and reset commands. Each relay provided an output to the Airlock telemetry system to indicate its status. The outputs from both of the receiver/decoders to the relay modules were in parallel and diode-isolated, with the exception of the two commands to the relays which controlled the receiver/decoders. The command to control the secondary receiver/decoder was available only from the primary receiver/decoder, and vice versa. Thus, a receiver/decoder could not command itself off.

(3) Command Relay Driver Unit (CRDU) - The CRDU utilized the Gemini stored program command capability of the receiver/decoders to provide additional real time commands. It decoded the first 10 data bits of the 24-bit stored real-time command and processed the command into a 200 millisecond, 850 milliampere pulse to actuate a latching relay. The last bit of the command was used to maintain odd parity. The remaining 13 data bits were not used.

The original command capacity of the CRDU was 256 commands. Redundant subunits were provided, each interfacing with a receiver/decoder and powered from a separate power supply. The command outputs from each subunit were connected to a single set of common output drivers in the original design. The current capacity of each driver in this unit was 600 milliamps. Later 12 additional one-ampere commands were added.

Inhibit circuitry was provided which, when activated by external switching, prevented blocks of commands from being executed. This feature was utilized for Electrical Power System commands to prevent their inadvertent activation by ground command when the crew was manually controlling.

The matrix selection method of the original design concept required switching of both the high and ground sides of each interfacing relay. The CRDU design was changed in the early stages of development to eliminate the ground side switching because it complicated selection between manual and command switching.

The CRDU provided digital outputs to the telemetry system to indicate the command message processed. This output was originally common to both subunits.

The capacity of the CRDU was increased to 396 commands as part of the conversion to a dry workshop. This increase was

required primarily because of new requirements for control of Environmental Control System functions and ATM deployment.

A final design change to the CRDU increased the command capability to 480 commands to meet new program requirements. At this time, the reliability of the unit was increased by elimination of single point failures. Each subunit was redesigned to contain its own output drivers and telemetry output circuitry. The output drivers for each command were connected, via diode isolation, to a common output pin. The telemetry outputs were tied to common pins via resistive isolation. The current capability of each of the drivers was changed to 850 milliamperes.

C. Test Results (DCS) - Acceptance and pre-launch tests of DCS subsystem flight equipment were successfully accomplished. There were no significant PIA problems with the DCS receiver/decoders or relay units. PIA of the CRDU was waived with the MDEC ATP satisfying the pre-installation test requirements. Systems level tests were performed as shown in Figure 2.10-2 for St. Louis tests and in Figure 2.10-3 for KSC tests. Significant problems resulting in replacement, modification, or repair of DCS subsystem equipment are as follows:

- DCS Receiver/Decoder - During the St. Louis simulated flight test when both primary and secondary DCS receiver/decoders were powered, real-time Channel #1 was actuated concurrently with every real-time command sent via the secondary DCS. Tests showed Channel #32 was similarly affected by the primary DCS. With both units powered, a sneak ground was caused by commonality between the vehicle address recognition logic and the real-time command logic in the decoders. DCS Channels 20 and 21 were reassigned to be used instead of Channels 1 and 32 respectively by modification of the vehicle wiring.
- Command Relay Driver Unit - During the KSC DA functional test, command S303 was transmitted; however, the downlink PCM indicated S016 was received. Troubleshooting indicated this condition occurred on the first command transmitted to the AM after command

subsystem power up and was caused by the secondary DCS receiver/decoder or side B of the CRDU. The S/N 104 secondary DCS receiver/decoder was replaced by S/N 106 causing no change in the condition. Further troubleshooting indicated the problem was a flip-flop in the data transfer logic of the CRDU that would occasionally stabilize in a set position when power was applied to the unit. The S/N 101 CRDU was returned to the vendor for incorporation of a diode in the interface and control logic of each CRDU side, which prevented erroneous clock pulses from being generated after power-up. This modification was incorporated in all CRDU flight units. S/N 100 was installed on U-1.

- DCS Receiver/Decoder - Also during the DA functional test, the DCS receiver/decoder S/N 106 failed to process commands. Troubleshooting indicated that the DCS receiver/decoder was not decoding the transmitted commands. S/N 106 receiver/decoder was replaced with S/N 104. The cause of the failure could not be isolated at the vendor to a piece-part level but was believed to be the failure of the receiver/decoder to reset after processing a received command, because of a malfunction in the program control board assembly. All suspect component parts were replaced.

D. Mission Results (DCS) - The Airlock DCS performed its intended function flawlessly throughout the manned and unmanned phases of the Skylab mission. Over 100 000 commands were successfully transmitted and executed; only one instance was reported of the failure of the DCS to execute a command. The DCS correctly received and processed all teleprinter messages and updates to the electronic timer. The primary DCS was utilized through most of the mission; the secondary system, although not required to meet mission goals, was powered up several times and its command capability was verified at least once during the mission.

(1) SL-1/2 - The DCS operated successfully throughout the mission. Both primary and secondary DCS were powered up from launch to DOY 137. The secondary DCS was powered down from DOY 137 to DOY 145 to conserve power. On day 145 the secondary DCS was activated to serve as backup for the SL-2 rendezvous and then powered down on DOY 146 and

remained powered down through the end of the mission.

(2) SL-3 - The DCS performed nominally throughout the entire SL-3 mission, with the primary DCS selected. Approximately 40,000 commands were successfully transmitted during the unmanned and manned portions of this period.

(3) SL-4 - The DCS performed nominally throughout the entire SL-4 mission except as noted below.

The DCS secondary system was powered up on DOY 273 for the storage period after SL-3 because the secondary electronic timer was also powered at this time and it was desired to maintain the DCS and electronic timer on separate buses to avoid a single point failure. The primary DCS was reactivated on DOY 323 for the SL-4 manned portion.

On DOY 315 DCS real time command 19-3 RESET (EXP 2/DATA 2 Recorder FAST FORWARD OFF) was sent and the function did not reset as it should have, as indicated by telemetry parameters K510 (Recorder #3 Motion) and K339 (EXP 2/D2 Recorder Fast Forward). The telemetry indicated that relay K6 in DCS relay module #3, which controls this function, failed to reset when commanded by the receiver/decoder. The relay was successfully reset on DOY 316 and usage of the command was avoided after that. Analyses were conducted by MDAC-E and the DCS vendor, Motorola, using the same type relays of the same vintage. The most probable cause of the problem was contamination between the relay armature and coil which prevented the relay from remaining in its reset state. MSFC conducted an analysis on 10 relays supplied by MDAC-E (from relay module S/N 121) and by Motorola and found loose particles of rosin flux in each of these relays.

As a result of the above malfunction, MDAC-E modified two tape recorder "Y" cables to delete the fast forward function. These cables were supplied to KSC for SL-4 stowage but were not flown because the relay had been successfully reset.

E. Conclusions and Recommendations (DCS) - The DCS performance during the Skylab mission was considered successful with only one incident reported of the failure to execute a command message.

Even though the performance of the DCS during flight verified the soundness of its design, some recommendations can be made for future programs. A new requirement for a DCS would most likely be met by a new design, employing state of the art techniques. The configuration of Airlock DCS hardware was chosen based on the desire to use previously designed equipment, and a more optimum configuration could be employed in a new design (for example, incorporation of CRDU functions, receiver decoder functions and relay module functions within one box; or separation by redundant units).

The usage of hardware designed for a previous program is a desirable practice which was proved successful by the performance of the DCS components, some of which were designed eleven years prior to the Skylab mission. However, such usage should be accompanied by an early development test program utilizing flight type hardware and wiring. This is especially important when a change in configuration from that originally designed for is required. The DCS receiver decoder, for example, was designed to be operated as a single unit. Although careful analysis was performed early in the program when two receiver decoder [illegible]re employed on Airlock, a logic incompatibility when operating [illegible] units simultaneously, alleviated by a vehicle wiring change to delete two command channels, was discovered late in the program. An early system level development test would have allowed this incompatibility to be discovered earlier, perhaps permitting a less constraining design change.

2.10.3.2 Teleprinter Subsystem

A. Design Requirement - The teleprinter was required in conjunction with the DCS to provide the capability of transmitting hard copy data from the ground to the crew.

B. Design History and Tradeoffs - The Skylab teleprinter was the first hard copy system utilized in a space application. Subsequent to the initial requirement, a survey of available commercial printing techniques limited the system selection to four basic categories. These were: electro-mechanical, photographic, magnetic, and thermal printers.

(1) Electro-mechanical printers consist of the type which drive full character font hammers, individual rods, imparting segmented mechanisms, or piezoelectric crystal driver characters.

(2) Photographic printers utilize fiber optics/cathode ray tube to expose light sensitive paper.

(3) Magnetic printing utilizes magnetic sensitive paper which produces marks corresponding to magnetic pulse inputs.

(4) Thermal printing utilizes an electrical pulse to energize heating elements which activate thermal sensitive paper to produce marks or dots.

Subsequent to the review of existing systems, design implementation, relative costs and evaluation by MDAC-E engineering, the thermal printing technique was selected and submitted to MSFC as the optimum system for utilization on Skylab. Although the preliminary study for a thermal spacecraft teleprinter was initiated under a NASA contract for application on Apollo, it was never implemented. Subsequent to these initial studies, MDAC-E engineering adapted the thermal printing technique to meet Skylab requirements. Primary objectives of the teleprinter development were the selection of paper, implementing packaging design/material selection, and interfacing with the existing DCS.

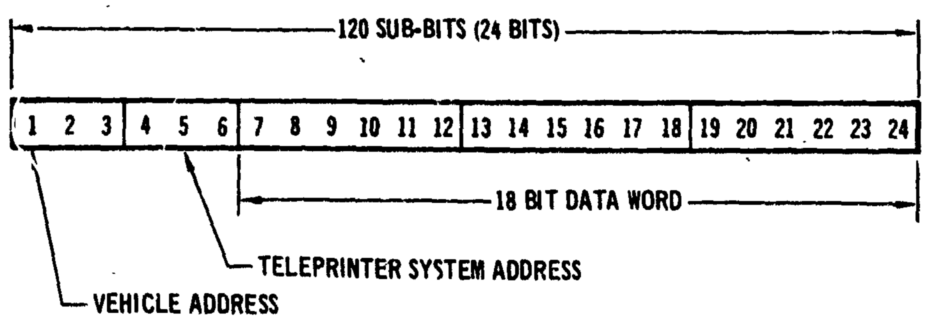
- Selection of a suitable paper required numerous test evaluations and long term endurance testing to assure environmental compatibility, durability, compliance with flammability requirements and quality of legibility. As a result of MDAC-E engineering studies, standard thermal coated military printer paper was selected as the optimum medium.

- Because handling and manipulation of the teleprinter functional components by the astronauts was required, prime consideration was given to packaging design and material selection with respect to dexterity, durability and compliance with metallic and non-metallic limitations. The major problem associated with the teleprinter material selection was the plating on the subsalient PM stepping motor. Standard commercial gold plating left the motor's permanent magnets and rotor extremely susceptible to high humidity. Consideration for the restriction of the electromagnetic flux and the necessity for minimizing the air gap made plating type and thickness critical. MDAC-E engineering evaluation and testing showed aluminum oxide plating (ion deposition process with a thin application of Braycote Micronic 803 grease) to be the optimum material.
- Interfacing with the existing DCS required an interface electronic unit (IEU) which received the coded digital serial data from either the primary or secondary DCS receiver/decoder, converted the data into dot matrix form and transferred the resultant data to the teleprinter.

C. System Description - The teleprinter subsystem received coded digital serial data from either the primary or the secondary DCS receiver/decoder, converted the data into dot matrix form and printed rows of dots on thermally sensitive paper. These dot rows were utilized to form 5 x 7 dot matrix characters with a maximum of 30 characters per line. The teleprinter subsystem provided Skylab with the capability of receiving printed messages using any combinations of sixty-two (62) alphanumeric characters at a maximum rate of 1855 characters per minute. The teleprinter paper was a minimum of 120 feet in length enabling a print capability of approximately 46,000 five letter words per roll. Skylab I was provided with a total of 156 rolls of teleprinter paper enabling a total message capability of approximately seven (7) million five letter words. The teleprinter subsystem provided telemetry signals for complete message, teleprinter input power, and teleprinter low paper. The teleprinter subsystem was

comprised of an IEU and a teleprinter.

(1) The IEU provided the interface conditioning between the DCS receiver/decoder and the teleprinter. The IEU accepted digital data in serial form from the DCS, converted it to the dot matrix format required by the teleprinter, and transferred the resultant information to the teleprinter for printing. The data from the DCS was in the form of a 24 bit serial message. The first 3 bits were vehicle addressed bits and were not accepted by the IEU. No information bits were provided the IEU unless a valid vehicle address had been identified in the decoder section of the DCS. The second 3 bits identified the system address and only data that was preceded by the teleprinter system address was accepted by the IEU. The remaining 18 bits of the serial message were stored in the IEU until sufficient messages were received to define a line of data (a full line required 180 bits of data), or a print execute message was received. The stored data was then decoded from the 6-bit American Standard Code for Information Exchange (ASC II) and encoded into the dot data required by the teleprinter. The format of DCS teleprinter messages is provided in Figure 2.10-8. Information for 3 characters was provided in every 18 bit data



NOTES: (1) VEHICLE ADDRESS FOR DCS 1 – 010
(2) VEHICLE ADDRESS FOR DCS 2 – 101
(3) TELEPRINTER SYSTEM ADDRESS – 001

FIGURE 2.10-8 TELEPRINTER SUBSYSTEM DATA FORMAT

word. The IEU assembled the alphanumeric information into 5 x 7 dot matrices and transferred the dot data to the teleprinter. The output of the IEU was such that the top row of dots for a character line was transferred first, then the second row of dots, etc., until the seventh row completed the line of characters. The IEU spaced the paper with 2 line feed signals between character lines. The first character sent from the DCS was printed on the extreme left side of the paper, followed by the second character, etc. In the case of a less-than-full line of characters, a print execute command identifies the end of the line.

(2) The teleprinter was a thermal dot printer producing hard copy messages by electrically heating print elements while in contact with thermally sensitive paper. There were 150 elements arranged in groups of five across the 3.25 inch wide paper. The printing process consisted of scanning serially from left to right across the 150 print elements (one dot row). Each dot pulse received by the teleprinter corresponded to a particular heating element. For each "logic one" received a thermal pulse was generated energizing the print element and subsequently marking the paper with a black dot. For each "logic zero" received, the corresponding area under the respective print element was left blank. When one line had been scanned, the paper was advanced and the 150 elements were again sequentially scanned. The process was repeated seven times to produce one line of alphanumeric characters. After the final print pulse in a dot row, a line feed pulse was used to advance the paper and reset the scale-of-ten counter so the next data group would be printed starting at the left side of the paper. Two extra line feeds were sent between character lines to provide paper spacing. Reference Figure 2.10-9 for a representation of the 62 alphanumeric characters available to the teleprinter subsystem and a copy of an actual message printed by a teleprinter.

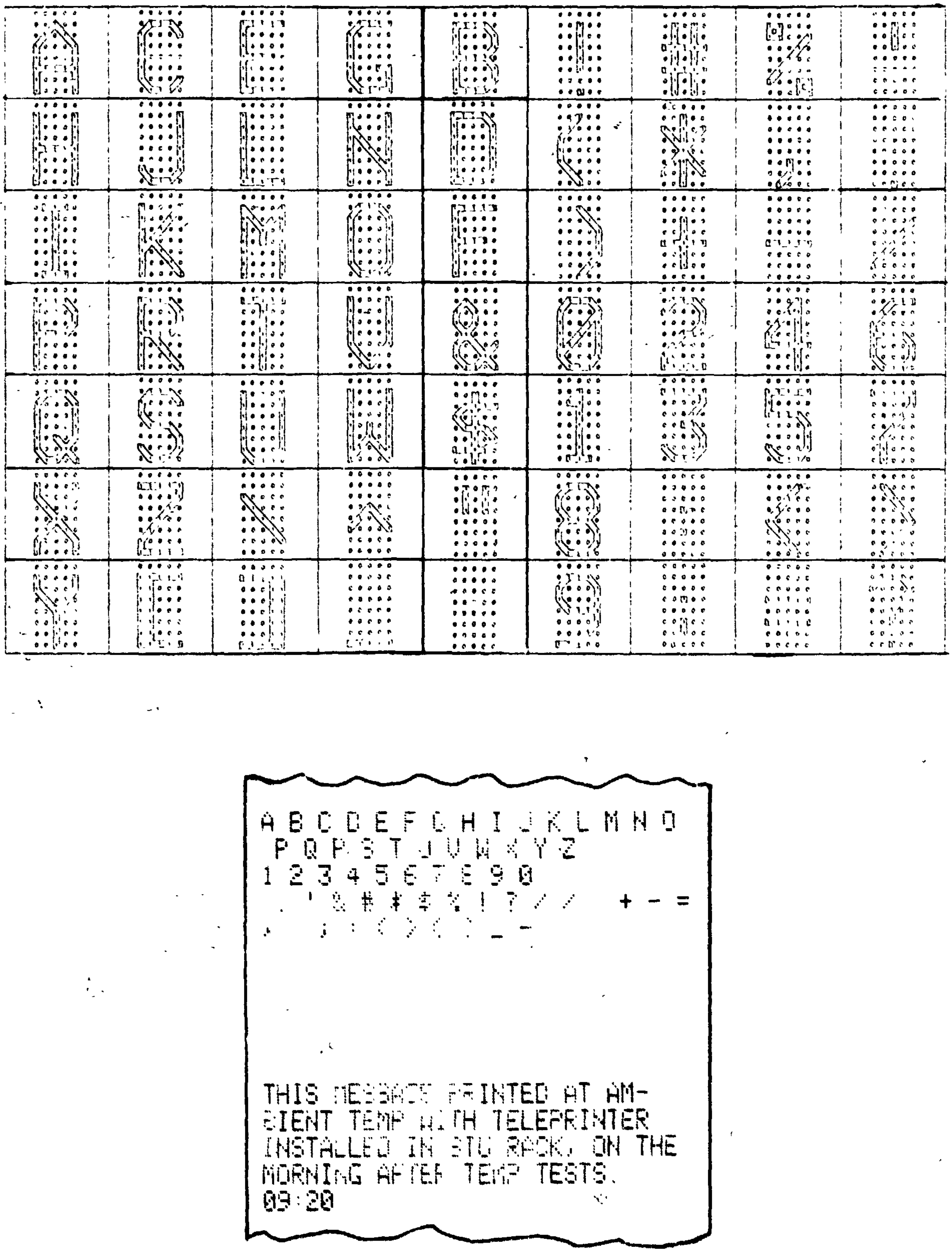


FIGURE 2.10-9 TELEPRINTER SYSTEM CHARACTERISTICS AND TEST MESSAGE

D. Test Results, Teleprinter - The teleprinter subsystem equipment successfully completed all test requirements for acceptance and pre-launch tests. Figure 2.10-2 shows the St. Louis test flow and Figure 2.10-3 shows the KSC test flow. The vendor ATP satisfied pre-installation test requirements of the IEU. There were two PIA teleprinter problems and one IEU installed systems level problem which resulted in equipment modification or repair as follows:

(1) During PIA testing at MDAC-E, S/N 101 teleprinter stopped operating while in the slew mode. An integrated circuit had failed due to a 38-volt spike on its input line that was generated when the slew switch was depressed. The problem was resolved by the addition of a RC filtering network on the input line. A similar failure in the S/N 10 qualification unit teleprinter preceded this S/N 101 failure.

(2) During PIA burn-in, S/N 101 teleprinter stopped printing. The problem was traced to a solder chip on a circuit board which was shorting between two contacts. The vendor was alerted to increase Q.A. surveillance and to include a vigorous shake-out of all units prior to final cover installation. Also during this PIA, the insulation measurement between the input voltage return line and chassis was low. A shorted EMI suppression feed-thru capacitor was found to be the source of the problem and was replaced.

(3) Interface Electronics Unit - In performing the retest of the DCS timer control relay panel at KSC, the teleprinter began to slew paper. Troubleshooting could not reproduce the problem. Testing at MDAC-E indicated the discrepancy was caused by erratic initialization of the print control logic circuitry which caused continuous line feed pulses to be generated by the IEU. The IEU was modified by utilizing an available gate to prevent turn on transients.

E. Mission Results, Teleprinter

(1) SL-2 - The teleprinter subsystem successfully performed its objectives from SL-2 activation through SL-2 deactivation. However, the first series of messages transmitted on DOY 146 were reported as being faint but legible. The next known comment was on DOY 148 and the crew reported "pretty good (print quality) this morning." This light printing was a direct result of the low temperatures in the AM STS at the time of SL-2 activation. Testing in the MDAC-E STU/STDN laboratory confirmed that the low temperature environment caused the light printing. When the AM temperatures stabilized in the normal vehicle range, the teleprinter message contrast returned to normal.

(2) SL-3 - The teleprinter subsystem was activated again for SL-3 on DOY 209. On DOY 219 the crew reported a teleprinter failure. The messages were compressed and unreadable because of the failure to advance the paper. The crew examined the teleprinter and found the paper drive roller was loose and unbonded from the drive bushing, thereby slipping and preventing transfer of motion to the paper. The crew replaced the failed teleprinter (S/N 104) with the onboard spare (S/N 100), which performed flawlessly, completing the SL-3 mission. The teleprinter drive roller failure was duplicated in the MDAC-E STU/STDN laboratory. Repair procedures and techniques were developed, utilizing onboard materials for use in case of failure of the replacement teleprinter. The MDAC-E STU/STDN laboratory was also used to produce video tapes to provide crew training information on the repair procedures. MDAC-E provided a teleprinter repair kit which was supplied to the SL-4 crew to be implemented in the event of a failure of the replacement teleprinter. Analysis of the design and manufacturing methods for the teleprinter drive roller assembly failed to reveal the cause for the drive roller/bushing separation. Without the availability of the failed assembly for [illegible]sis, MDAC-E could not fully determine cause for the [illegible]

(3) SL-4 - The teleprinter subsystem was activated again for SL-4 on DOY 321 and performed satisfactorily except for one occasion. On DOY 338 the crew reported printing problems after they resupplied the teleprinter with paper. Subsequent to the paper replacement, the crew reported only partial printing of the transmitted messages. The teleprinter cartridge and paper was replaced and the messages retransmitted. The crew reported the printout as readable but faint, requiring some clarification from the ground. On DOY 342 the teleprinter was resupplied with a new roll of paper and the crew reported the messages as being "clear, sharp, and dark." The light and partial printing encountered was believed to be the result of two separate factors. The first report of partial printing was most likely a direct result of paper misalignment and coneing of the paper roll by the crew during replacement. After the crew replaced the misaligned paper with a new roll, the teleprinter started printing light. The cause for the light printing after the replacement of the cartridge could not be determined. After the replacement of the degraded roll of paper the teleprinter printing returned to normal.

F. Conclusions and Recommendations, Teleprinter - The teleprinter subsystem performed its intended function satisfactorily throughout the Skylab mission, with the three noted exceptions, providing the crews with retainable, hard copy messages. The high usage of the teleprinter for sending hard copy updates of flight plans, crew procedures, etc., verified the desirability of such a device on manned space missions.

2.10.3.3 Time Reference Subsystem (TRS)

A. Design Requirements - The TRS was initially required to provide an elapsed time output for the Instrumentation System and a variable time delay control function for resetting command relays. A second variable time delay control function was subsequently required to switch redundant DCS receiver/decoders. The addition of the EREP and of crew GMT displays in the AM and OWS required further usage of the elapsed time output resulting in the need for new display and buffer equipment. A resettable timer was also included to assist the crew with time keeping functions. Reliability considerations of mission requirements dictated the need for redundant TRS equipment.

B. TRS Design History, Tradeoffs and Design Description - The original TRS consisted of one electronic timer which provided time correlation data to the PCM multiplexer/encoder.

With the addition of a redundant DCS, the TR-30 seconds output of the electronic timer was used to automatically select the standby DCS. An auxiliary timer was also added to provide automatic DCS switchover after a predetermined time period, in case of electronic timer failure during orbital storage. This method was used in lieu of powering both DCS's continuously, which would have reduced reliability and required more power.

Later during the design phase a secondary electronic timer was added to provide redundant time correlation data to the PCM multiplexer/encoder. Selection of electronic timers was controlled by the DCS. The secondary electronic timer TR-30 seconds output was also available to provide the redundant automatic switchover capability to the standby DCS. Therefore, the auxiliary timer was deleted. This design change increased DCS reliability and also reduced power consumption.

The TRS was later expanded to provide time correlation data to EREP and to provide two clock displays of GMT. The clock displays were to be located in the STS C&D Panel and OWS C&D Panel areas.

Ground control and inflight control capability for synchronizing TRS elapsed time with GMT were also provided. This addition created the time correlation buffer (TCB) and the digital display unit (DDU). The TCB converted the electronic timer elapsed time serial binary data into binary coded decimal (BCD) data for the EREP and DDU's.

The flight configured TRS shown in Figure 2.10-6, consisted of two electronic timers, two TCB's, one digital clock, and two DDU's. One additional DDU was stowed on-board as a flight spare. A description of these components follows:

(1) The two electronic timers were powered from separate buses. During the mission, one electronic timer was active while the other was retained in inactive standby. Timer selection was made by the DCS. The electronic timer provided the following outputs: elapsed time (ET) data to the PCM multiplexer/encoder and to the TCB; a countdown of time-to-go-to redundant DCS switchover (Tr) with a relay closure to control the redundant DCS; a countdown of time-to-go-to equipment reset (Tx) with a relay closure to the DCS for resetting relays controlling various equipment; and 8 pulses per second data to the digital clock. The Tx output was also required for synchronization of ET zero with midnight GMT when command enabled. Both ET and Tr were monitored by telemetry. The electronic timer was basically an electronic binary counter which contained three separate magnetic registers to provide nonvolatile memory. The electronic timer performed the function of counting up time and counting down time by an add/subtract program which was repeated every 1/8 second. The electronic timer had an accuracy of $\pm$.875 seconds per day if the temperature was held to 25°C $\pm$ 10°C. If the unit was allowed to traverse the temperature extremes of -29°C to +93°C, the inaccuracy of the timer could go as high as 3.125 seconds per day. This deviation was primarily caused by the internal crystal oscillator variations over this temperature range. Therefore, all the registers in the timer would be off in the same direction (fast or slow) by the same percentage. The function of the electronic timer's three shift registers ET, Tr, and Tx were as follows:

- ET counted up elapsed time which was transferred serially upon request to the PCM multiplexer/encoder or the TCB. The ET register could be reset to zero manually or from the ground via the Tx output but could not be updated. The ET register contained 24 bits and had a maximum value of 582 hours, 32 minutes and 31 7/8 seconds.
- Tr counted down from a preset value which was loaded into this register by the DCS. The Tr data was transferred serially upon request to the PCM multiplexer/encoder. At Tr = 30 sec, the electronic timer provided a discrete output for automatic switchover to the redundant DCS receiver/decoder. Operationally, the Tr register was periodically updated by the DCS to prevent reaching switchover with the DCS working properly. The Tr register contained 24 bits and had a maximum value of 582 hours, 32 minutes and 31 7/8 seconds.
- Tx counted down from a preset value which was loaded in this register by the DCS. At Tx = 0, the electronic timer provided a discrete output to the DCS receiver/decoder which automatically reset preselected DCS real time commands. When Tx = 0 was used in conjunction with the DCS TRS ET reset command, the discrete output from the electronic timer automatically reset the ET register to zero. The function synchronized ET zero with midnight GMT. During the duration of this discrete pulse, the Tr register was inhibited from decrementing. The ET zero reset function could also be performed manually with the Zero Reset Switch. The Tx register stopped counting at Tx = 0 and remained at zero until updated via the DCS. An exception to this occurred when an electronic timer was turned on with the contents of the register previously zeroed. This operation inserted a maximum value of Tx into the register. The Tx register contained 16 bits and had a maximum value of 2 hours, 16 minutes and 31 7/8 seconds.

(2) The two TCB's were powered from separate buses. Selection of either the primary or the secondary TCB was accomplished by on-board switching. The TCB operated in conjunction with the

electronic timer to provide time data for the EREP and the DDU's. The TCB converted the serial 24 bit binary elapsed time word from the electronic timer into two types of BCD outputs. A serial 36-bit time word was provided to EREP 64 times a second. This time data corresponded to days, hours, minutes, seconds and fractional seconds through 1/64. The TCB also supplied a synchronization pulse every 1/32 of a second to EREP for input data synchronization. The TCB provided a serial 30-bit BCD data word to the DDU's once every second. The 30-bit data word information consisted of days, hours, minutes and seconds with a LSB value of 1 second. ET data was shifted from the electronic timer 8 times a second upon request from the TCB. There were 3 switches, i.e. 1 day, 10 day and 100 day, provided to manually update the TCB day register. The TCB contained a crystal oscillator identical to the electronic timer's and was synchronized with the electronic timer 8 times a second. Therefore, accuracy of the data to EREP and DDU's was equal to the electronic timer when compensated for processing delays.

(3) Two DDU's were provided; one located in the AM STS, the other in the OWS. Their function was to display GMT in days, hours, minutes and seconds. The two DDU's interfaced with the active TCB on separate lines and the interface lines were automatically switched to the TCB selected. Time data was shifted from the TCB to the DDU once per second with a LSB of 1 second. The DDU decoded and converted the BCD information into drive logic for light emitting diodes which formed the time decimal display. The power to the DDU and brightness of the display were manually controlled by the crew.

(4) The digital clock located in the AM STS, received an 8 PPS signal from the active electronic timer. The clock was basically an electronic stop watch with a motor controlled display and was available to the crew for time keeping functions. The clock was preset by the crew to any desired time between zero and 999 hours, 59 minutes and 59 seconds. The clock was motor driven by power pulses that were synchronized to the 8 PPS from the electronic timer.

Therefore, the accuracy of the digital clock was the same as the electronic timer. The digital clock was manually controlled.

C. Test Results (TRS) - Acceptance and pre-launch tests on the TRS were successfully accomplished. Figure 2.10-2 shows the St. Louis test flow and Figure 2.10-3 shows the KSC test flow. The PIA of the TRS equipment was waived with the vendor ATP satisfying the pre-installation test requirements. Significant TRS equipment test problems resulting in equipment modification or repair were as follows:

(1) Time Correlation Buffer - During systems level tests at St. Louis, the DDU day count of TCB S/N 102 indicated extraneous day increments during the simulated flight test and random displays were reported during the altitude chamber test. Fault isolation indicated that the minutes and hours of the TCB were occasionally incorrect, once or twice a day. Random changes to the hour position of the time word caused the day count to increment when the day count flip-flop was set. The binary-to-BCD converter was noise susceptible. For noise reduction, modifications of the TCB were made by installing a second set of power line EMI filters and by adding capacitors to the internal power supply. Isolation of noise from the signal lines were improved by more shielding, by shorter ground paths and by twisting and rerouting power lines.

(2) Digital Clock - Digital clock accuracy was out of tolerance during the systems validation test at St. Louis. The accuracy of the digital clock was affected by random noise through the clock's power return during the fall time of the 8 PPS signal within the digital clock. A 47K ohm resistor across the data input line improved, but did not eliminate, this inaccuracy. The resistor was removed and the digital clock was modified to eliminate the problem by installing a jumper wire which utilized an available "one-shot" multivibrator to ground the input inverter during the fall time of the 8 PPS signal.

(3) Electronic Timer - During the retest of the DCS timer control relay panel at KSC, a Tx update of one minute resulted in a two minute update. A Tr update of 500 hours was transmitted and the resultant update was 417 hours, 27 minutes and 28 seconds.

The secondary electronic timer was replaced with a ground spare unit. Tx and Tr messages then accurately updated the TRS. The discrepant timer was found to have a broken wire which allowed the update control to start anytime during the first bit time rather than at the start of the bit time. Missing the first bit resulted in the other 23 data bits being one bit behind in the electronic timer register. The probability of this problem occurring in the faulty timer was about 2% of the time.

D. Mission Results (TRS) - The TRS operated considerably better than the error specification of less than ± 3 seconds per day. The elapsed time error for the primary electronic timer averaged approximately 0.25 seconds per day (fast) while the secondary timer averaged approximately 0.4 seconds per day (slow). The primary and secondary timers were operational for the entire mission duration of 6507 hours. The time correlation buffer, the DDU's and the digital clock were powered for 4024 hours throughout the manned phases. Two timing discrepancies occurred during the SL-3 mission:

(1) A primary electronic timer discrepancy occurred after approximately 2478 hours of continuous operation. The crew reported that the AM and OWS digital display units counted erratically. Timing to other systems was observed to be normal (EREP was not activated). The erratic DDU readouts occurred following installation of the rate gyro six-pack and were suspected to be EMI related. The secondary electronic timer was activated and normal timing was restored.

(2) The secondary electronic timer elapsed time data became erratic after approximately 583.6 hours of operation. The primary electronic timer was reactivated and normal timing data was restored.

A review of the telemetry data indicated that elapsed time magnetic shift registers were permanently altered five times in a random manner. The Tr data during the time of these failures was normal. Reactivation of the secondary electronic timer indicated that this timer had returned to satisfactory operation. The failure cause was unknown and was unique to the secondary electronic timer. Testing at vendor facility could not duplicate

the discrepancy. Since this anomaly occurred during period of high activity in Skylab it too was suspected to be EMI related. No operational changes resulted. The primary and secondary timers both operated nominally during the SL-4 mission.

E. Conclusions and Recommendations (TRS) - The TRS met all design goals during the Skylab missions. The system was operational throughout the mission and satisfactorily provided a time base for the Instrumentation System, crew displays and EREP. In addition, all variable time delay control functions operated nominally.

The following items were identified during system testing and/or mission support activities and recommended to further improve the capabilities of the TRS.

(1) The electronic timer and time correlation buffer should be incorporated into one unit. This change would decrease the weight, improve reliability and decrease EMI susceptibility.

(2) DCS update capability for the elapsed time register should be added in the electronic timer so that synchronization to GMT could be performed at any ground station. This would eliminate synchronization of electronic timer elapsed time register by the electronic timer Tx output at midnight GMT.

(3) Expand the telemetry readout capability to monitor the electronic timer's Tx register, EREP and DDU timing data so that failures could be analyzed from the ground more effectively.

2.10.4 Rendezvous and Docking Subsystems

2.10.4.1 Rendezvous and Docking Subsystems Design Requirements

The rendezvous and docking subsystems include a VHF ranging subsystem, tracking lights, and docking lights.

A. VHF Ranging Subsystem - The VHF Ranging Subsystem was required to determine the range and range rate between vehicles in cooperation with the existing Apollo VHF/AM transponder equipment. A new ranging antenna was required to provide the necessary RF signal margins to facilitate the rendezvous of the Command Modules with the Saturn Workshop.

B. Tracking Lights - The tracking lights were required to provide the crews in the CSM with a means of visually locating the SWS during night portions of the rendezvous, in conjunction with the Apollo sextant, or with the crew Optical Alignment Sight (COAS) as a close-range backup. The requirement for these lights was created as a result of a vehicle redesign which eliminated four acquisition lights originally installed on the OWS.

C. Docking Lights - The docking lights were required to provide the CSM crews with orientation and alignment information during final docking maneuvers.

2.10.4.2 Rendezvous and Docking Subsystems Description

A. VHF Ranging Subsystem - The VHF ranging subsystem (see Figure 2.10-10) consisted of a VHF transceiver assembly and a ranging tone transfer assembly (RTTA), which were previously developed on the Apollo program. The changes employed on these units for the Skylab program were the replacement of a connector on the transceiver, to preclude the possibility of improper cabling to the unit, and bypassing the contacts of an unused relay to prevent the possibility of degraded RF output as a result of relay contact contamination. The power supply for the RTTA was redesigned to preclude the possibility of an overcurrent sensor being activated by bus transients and automatically shutting down the RTTA.

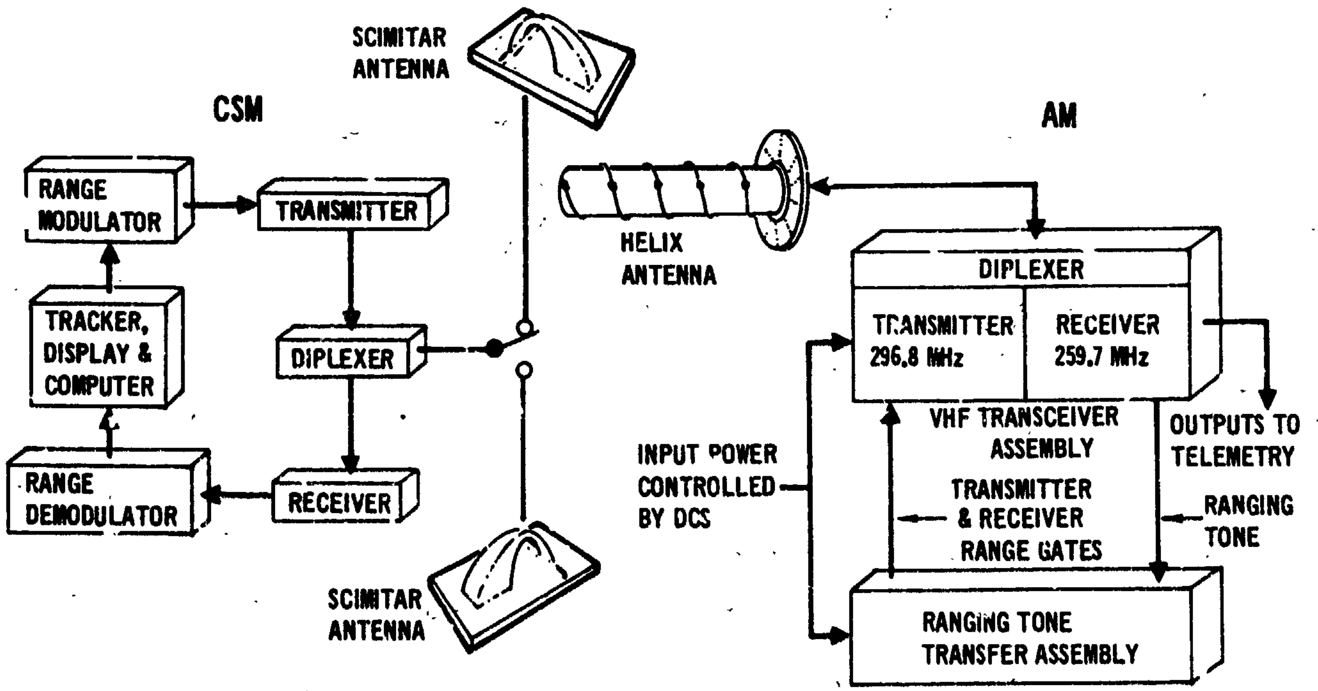


FIGURE 2.10-10 VHF RANGING SUBSYSTEM

(1) The VHF ranging subsystem was enabled by DCS command during the rendezvous sequences. The operational sequence of the ranging subsystem was as follows:

A 3.95 KHz tone, amplitude modulated on a 259.7 MHz carrier, was transmitted from the CM. When this tone was demodulated by the AM transceiver it was detected by a sensor in the RTTA. The activation of this sensor allowed direct retransmission of the 3.95 KHz tone on the 296.8 MHz transmitter in the AM. As this transponded tone was received by the CM, it allowed mid-range tracking which initiated transmission of a modulo-2 combination of the 3.95 KHz signal and a 247 Hz signal. This combined signal was received by the AM and was again transponded back to the CM. When this combined transponded signal was received by the CM, unambiguous range tracking was possible with the 247 Hz signal as well as mid-range tracking with the 3.95 KHz tone.

Automatic tests were performed by the CM equipment to insure proper lock-up of the mid and coarse range tracking loops. When proper tracking was confirmed, a 31.6 KHz tone was transmitted from the CM. A 31.6 KHz tone generated in the RTTA was maintained in synchronization with the 31.6 KHz signal received from the CM. This corrected or synchronized 31.6 KHz signal was transmitted to the CM. When it was received, the phase difference between the original CM-transmitted 31.6 KHz signal and the AM synchronized 31.6 KHz signal, minus the predetermined (by testing) value of fixed delays, provided range determination between the vehicles. The maximum unambiguous range was nominally 300 nautical miles.

(2) The RTTA required an input power of 4.3 watts of unregulated voltage (24-30 VDC) and was located on Electronics Module 5. The VHF transceiver required an input power of 33.5 watts of unregulated voltage (24-30 VDC) and was located on Electronics Module 5.

(3) VHF ranging helix antenna was installed on the ATM Deployment Assembly. The antenna was circularly polarized and had a 3 dB beam width of approximately 50° and a minimum of 8.0 dB gain at

259.7 MHz and 9 dB gain at 296.8 MHz. The antenna assembly consisted of two major parts, a five turn helix and a ground plane. The five turn helix was approximately 53 inches long and 14 inches in diameter. It was centered on a circular plane of 32 inch diameter.

B. Tracking Lights

(1) Four tracking lights, two primary and two secondary, were provided. Each light consisted of a flash head and an electronics unit. The four flash heads were mounted on the AM Deployment Assembly, two on each side of the MDA, near the SWS Y-axis (Figure 2.10-11), and the electronics units were mounted on Electronics Module #6. Each light provided a 90° cone of light centered on the SWS +X-axis, with a minimum light intensity of 1000 beam candle seconds. The lights flashed at a rate of 50-65 flashes per minute, with a maximum flash duration of 0.3 millisecond. The primary lights were synchronized with each other, as were the two secondary lights, but synchronization did not exist between primary and secondary lights.

(2) The tracking lights selected were a modified version of the lights used on the Apollo program. A number of changes were required to the lights to produce the increased light intensity required for the Skylab program. The higher light intensity requirements created certain design problems, such as operating in the corona region and meeting the requirements of the Electromagnetic Compatibility Control Plan for the Airlock.

The operation of the lights also created a personnel eye damage hazard which required the successful employment of operational constraints, such as shielding the lights during test operations and turning them off when the CSM was in close proximity to the SWS.

(3) A block diagram of the tracking lights is shown in Figure 2.10-11. Control of the lights was normally provided by the DCS; however an onboard switch was available for crew control if required. Automatic switchover circuitry provided automatic switchover to the secondary lights in event of a malfunction in the primary lights.

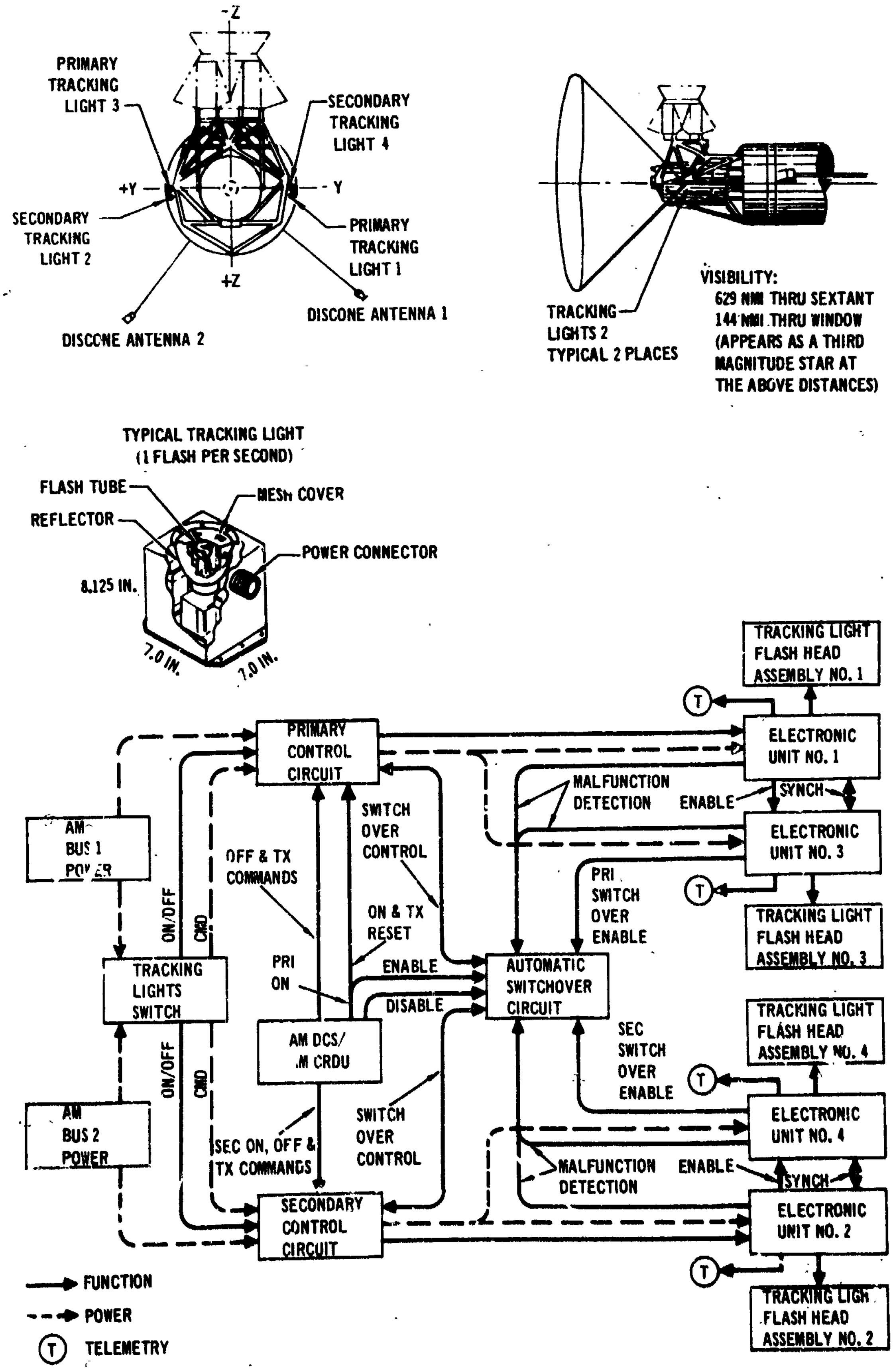


FIGURE 2.10-11 TRACKING LIGHTS

If the secondary lights were selected, this circuitry energized all remaining lights in event of a secondary malfunction.

An alternate means of "off" control for the tracking lights was provided by the electronic timer Tx function, to provide for termination of operation when the spacecraft was out of range of a tracking station (Reference para. 2.10.3.3).

The primary and secondary tracking lights were powered from alternate buses. Each electronics unit required 180 watts maximum of unregulated power and supplied 80 watts to the flash head.

C. Docking Lights - Initially the docking lights consisted of eight lights. Four mounted on the FAS and four mounted on the MDA, Figure 2.10-12. The lights were color coded to aid the crew in orienting the CSM for final rendezvous and docking maneuvers. Subsequently the discone antenna docking lights were added which acted as visual locators for the crew so the antennas could be avoided during fly around and docking maneuvers. The capability of powering the white AM docking light from the EVA lighting system, paragraph 2.12, was added.

Although the lights were normally controlled via the DCS, an onboard switch provided the capability for crew control in the event of an EVA or a CSM rescue mission. AM bus 1 powered half of the docking lights, with the remainder powered by AM bus 2. The individual lights were not redundant since the loss of several lights would not hamper docking.

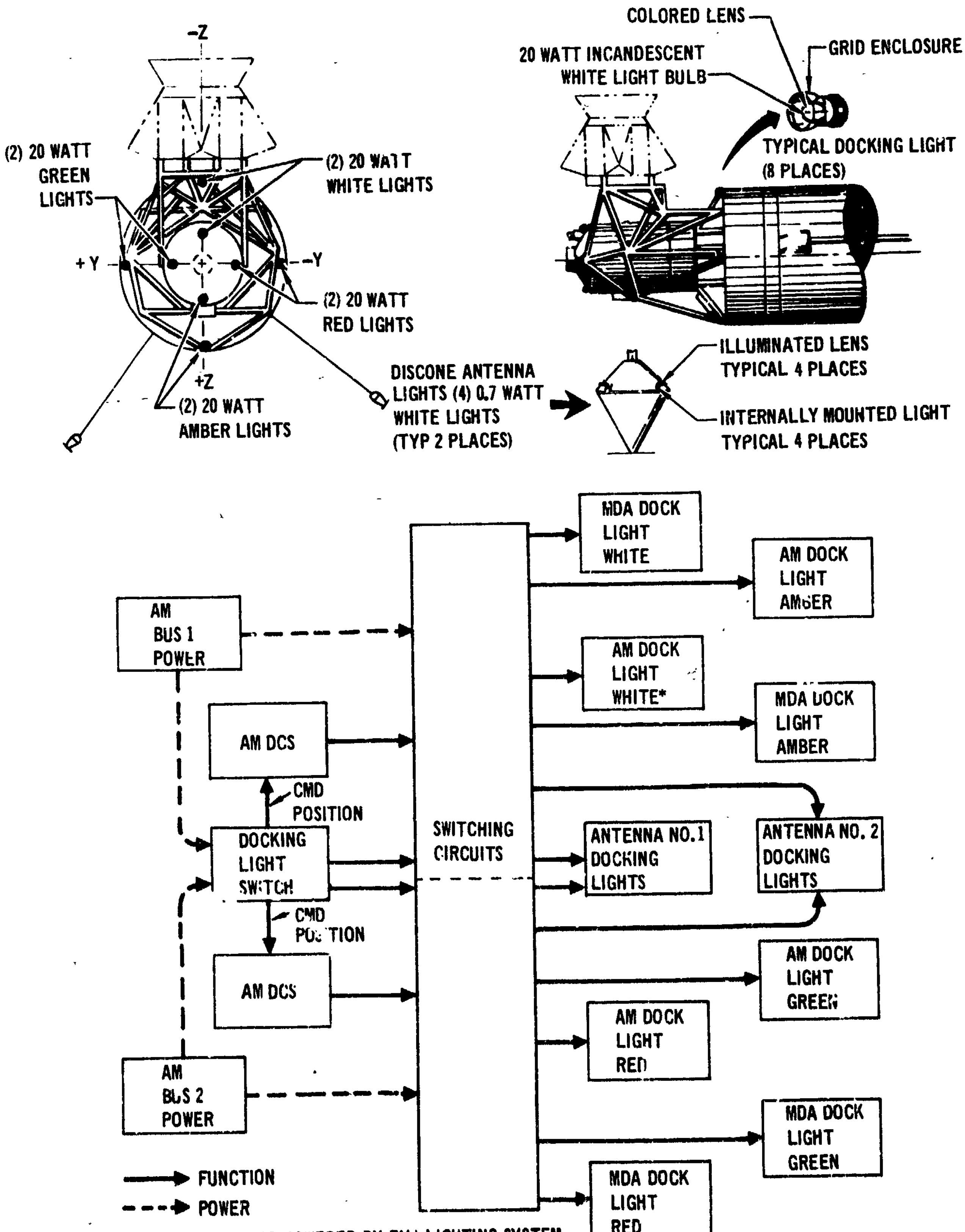


FIGURE 2.10-12 DOCKING LIGHTS

2.10.4.3 Rendezvous and Docking Subsystems Testing

A. VHF Ranging Subsystem

(1) The Ranging Transceiver and RTTA were obtained from the vendor as separate units and were PIA-tested together at MDAC-E prior to installation. The same test bench used to conduct these preinstallation tests was used to support system level tests after installation.

Bench level tests were performed at St. Louis on the VHF transceiver assembly, the ranging tone transfer assembly, and the ranging antenna.

The ranging tone transfer assembly and the ranging antenna met all PIA test requirements without significant problems. Problems associated with the VHF transceivers were as follows:

- VHF transceiver S/N 100 RF power output fluctuated between 3.2 watts and 5.8 watts. Failure analysis determined the cause to be improper grounding within the transceiver. A change in vendor assembly sequence resolved the problem.
- VHF transceiver S/N 101 exhibited the same grounding problem as S/N 100 plus crosstalk which was traced to defective capacitors. These capacitors were removed from S/N 100 and S/N 101 transceivers and replaced with units having tighter quality control.

(2) System level tests at St. Louis of the VHF ranging subsystem were performed to demonstrate the ability to perform successfully in expected flight modes and sequences. The St. Louis System test flow is shown in Figure 2.10-2. VHF ranging subsystem test requirements were successfully demonstrated during systems validation, systems assurance, and simulated flight tests. The VHF ranging equipment supported other system level tests including ranging verification by hardline operation during the altitude chamber test. No significant problems resulted from AM U-1 ranging subsystem tests at St. Louis.

(3) Launch Site Tests at KSC on the VHF ranging subsystem were successfully accomplished during system level and integrated testing at KSC. The KSC System flow followed is shown in Figure 2.10-3. Ranging subsystem operation was demonstrated by hardline through a delay unit with the CM in the MSOB and open loop between the AM in the VAB and the CM on Pad 39B. No significant problems resulted from these tests.

B. Tracking Lights

(1) MDAC-E PIA tests, including functional tests and light intensity tests, were performed on each tracking light assembly (flash head, electronics and cable) prior to installation. During St. Louis Systems tests, the installed systems were operated to verify compatibility with other operating systems, including verification at simulated altitude. St. Louis test flow is shown in Figure 2.10-2.

The tracking light subsystem was successfully verified for the following total system functions:

- Individual flash rate and flash synchronization of the tracking lights
- Primary and secondary system operations
- Automatic switchover circuitry operations
- Manual and CMD system operation
- Tx timeout functional interface circuitry
- Overall integrated system/EMC compatibility

(2) KSC - The tracking lights were successfully tested at the launch site. No significant problems were encountered.

C. Docking Lights - The docking lights were also successfully tested at MDAC-E and KSC. All prime and redundant circuits were verified for illumination and end-to-end operation. Command and manual control of the docking and antenna lights was also verified. The docking lights were activated during a simulated mission profile and at simulated altitude.

2.10.4.4 Mission Results - Rendezvous Subsystem

A. SL-2 - The VHF ranging and tracking light subsystems operated during the SL-2 rendezvous for three hours and two hours, respectively, on DOY 145. During rendezvous, the Skylab was in a 50° pich-up attitude for OWS thermal control. The 130 nautical mile acquisition range, reported by the crew for both systems, is considered very satisfactory in view of this off-nominal viewing angle. The VHF ranging system was operated for approximately 234 hours to provide heat into the AM coolant loop, to compensate for the abnormally low external and internal heat loads resulting from vehicle orientation and lack of sufficient heat load on the cooling system because of vehicle power shortage. The docking lights were successfully operated from the terminal phase of the rendezvous and remained operational until SL-1/2 docking.

B. The VHF ranging and tracking lights subsystem were operated successfully during the SL-3 rendezvous on DOY 209. The VHF ranging subsystem was activated at 14:22 GMT and initial acquisition occurred at a range of 390 nautical miles, which is in excess of the 300 nautical mile specified maximum range. The tracking lights were activated at 14:23 GMT and were first sighted and reported by the the crew at the same 390 nautical mile range, which is also in excess of the expected range.

This rendezvous was conducted with the SWS in a solar inertial attitude because of the reduction of solar power-generating capability as a result of loss of one OWS SAS wing. This profile was altered from the pre-mission plan in which the SWS was in a Z-local vertical attitude during much of the time the rendezvous systems were to be active. The solar inertial attitude caused some off-nominal look angles for both the VHF ranging subsystem and the tracking lights, resulting in some predictable periods of loss of contact between the CSM and the SWS.

The docking lights operated nominally for approximately 2 hours from the final portions of the rendezvous until SL-1/3 docking.

C. The VHF ranging and tracking light subsystems were operated successfully during the SL-4 rendezvous on DOY 320 for approximately four hours. Ranging acquisition was first attempted, successfully, at a reported range of 209 nautical miles. No indication was reported by the crew as to when the tracking lights were first sighted.

The rendezvous was conducted with the SWS in a solar inertial attitude, as in the SL-3 rendezvous. Again, some predictable periods of loss of contact were encountered because of the resulting off-nominal look angles.

The docking lights were operated for approximately 1.5 hours until the CM was docked to the SWS.

2.10.4.5 Conclusions and Recommendations

Conclusions - The VHF ranging subsystem performed normally during the Skylab mission indicating that hardware developed for other space programs can be applied to later programs with good results. The tracking lights performed normally during this Skylab program without the utilization of backup hardware.
Recommendations - Development of hardware should be structured toward future applications on many programs, i.e., standardization of space hardware should be attempted.

2.11 CAUTION AND WARNING SYSTEM

The Saturn Workshop (SWS) Caution and Warning (C&W) System provided the crew with visual displays and audible tones when specified cluster parameters reached out-of-tolerance conditions.

The original C&W System design concept consisted of a Call and Warning Unit and an alarm tone generator that was part of the Gemini Voice Control Center. Initially, only twelve parameters were to be monitored. System sensors and associated electronics were nonredundant. Later, the system was modified to consist of an Emergency and Warning Unit capable of monitoring 35 parameters, including fire and rapid loss of vehicle pressure. Redundant sensors and electronics were added along with two klaxons for providing emergency tones. Finally, the C&W System was expanded to contain redundant subsystems within a caution and warning unit. Seventy-six selected parameters were monitored and four separate audio tones, along with visual indicators, were provided.

The MDAC-E effort regarding this system included the following:

A. Design and development of the C&W System.
B. Performance of the integration effort required for defining and evaluating the AM, ATM, MDA and OWS C&W System for compliance with cluster requirements.
C. Qualification of system components and verification of system performance.
D. Performance of C&W System support activities for all Skylab missions.

2.11.1 Design Requirements

The finalized requirements for the C&W System are defined in the Cluster Requirement Specification, RS003M00003, Appendix H. A summary of these requirements is presented below.

2.11.1.1 C&W System Purpose

The C&W System for the cluster (CSM docked to SWS) was required to monitor the performance of itself (voltage only) and other selected systems parameters, and alert the crew to imminent hazards or out-of-limit conditions which could result in jeopardizing the crew, compromising primary mission objectives, or, if not responded to in time, could result in loss of a system. Parameters monitored by the C&W System were to be categorized as either EMERGENCY, WARNING, or CAUTION. When any of the parameters reached the predetermined out-of-tolerance level appropriate visual and acoustical signals were to be activated.

2.11.1.2 C&W Subsystems

Each vehicle (SWS or CSM) C&W System was to consist of the following:

A. Emergency Subsystem - The emergency subsystem was to alert the crew to defined emergency conditions which could result in crew injury or threat to life and required immediate corrective action, including predetermined crew response. The emergency subsystem was to alert the crew by triggering an acoustical alarm system within the vehicle atmosphere and by providing typical warning category outputs. The emergency subsystem was to be DC isolated from the caution and warning subsystem.

B. Caution and Warning Subsystem - The caution and warning subsystem was to alert the crew to defined caution or warning out-of-tolerance conditions. All outputs of the caution and warning subsystem were to be displayed on the caution and warning system panel(s) and were to generate the appropriate caution or warning tone for routing to the crewman earphones and speaker intercom assemblies (SIA's). The caution or warning conditions were defined as follows:

   (1) Caution - Any out-of-limit condition or malfunction of a cluster system that could result in not meeting primary mission objectives or could result in loss of a cluster system if not responded to in time. Crew action was required although not immediately.

(2) Warning - Any existing or impending condition or malfunction of a cluster system that would adversely affect crew safety or compromise primary mission objectives. Immediate action by the crew was required.

2.11.2 System Description

The design features and major components of the C&W System are described below; detailed description of this system is contained in the Skylab Caution and Warning Technical Manual, MSFC 40M35701.

2.11.2.1 Skylab C&W System

The Skylab C&W System consisted of C&W Systems installed in both the SWS and the CSM. Each system provided the crew with visual displays and audio tones when selected parameters reached out-of-tolerance conditions. In the docked configuration, the two C&W Systems interfaced by means of discrete contact closures to provide for cluster wide monitoring of selected parameters. The C&W System equipment used to monitor these parameters is depicted in block diagram form in Figure 2.11-1. The SWS C&W System control and display panels are shown in Figure 2.11-2.

A. SWS C&W System - The system monitored the performance of specified vehicle systems and alerted the crew to hazards or out-of-limit conditions. The SWS C&W System utilized two independent subsystems, a caution and warning subsystem for monitoring various system parameters and an emergency subsystem for detecting fire or rapid loss of pressure.

B. CSM C&W System - The CSM contained a separate C&W System for monitoring thirty-six critical system parameters in the CSM. An out-of-tolerance condition in the CSM resulted in the generation of audio tones and the illumination of visual displays in the CM. In addition, the CSM C&W System provided redundant contact closures to the SWS C&W System. Upon receiving the CSM inputs, the SWS C&W System activated the corresponding SWS warning audio tone and illuminated the visual displays to alert the crew so that corrective action could be taken. The audio tones continued until the SWS C&W System was reset; however, the CSM closure remained until reset from within the CM. The CSM C&W equipment and operation is discussed in detail in the Skylab Operations Handbook, Volume I, SM2A-03-SKYLAB-(1).

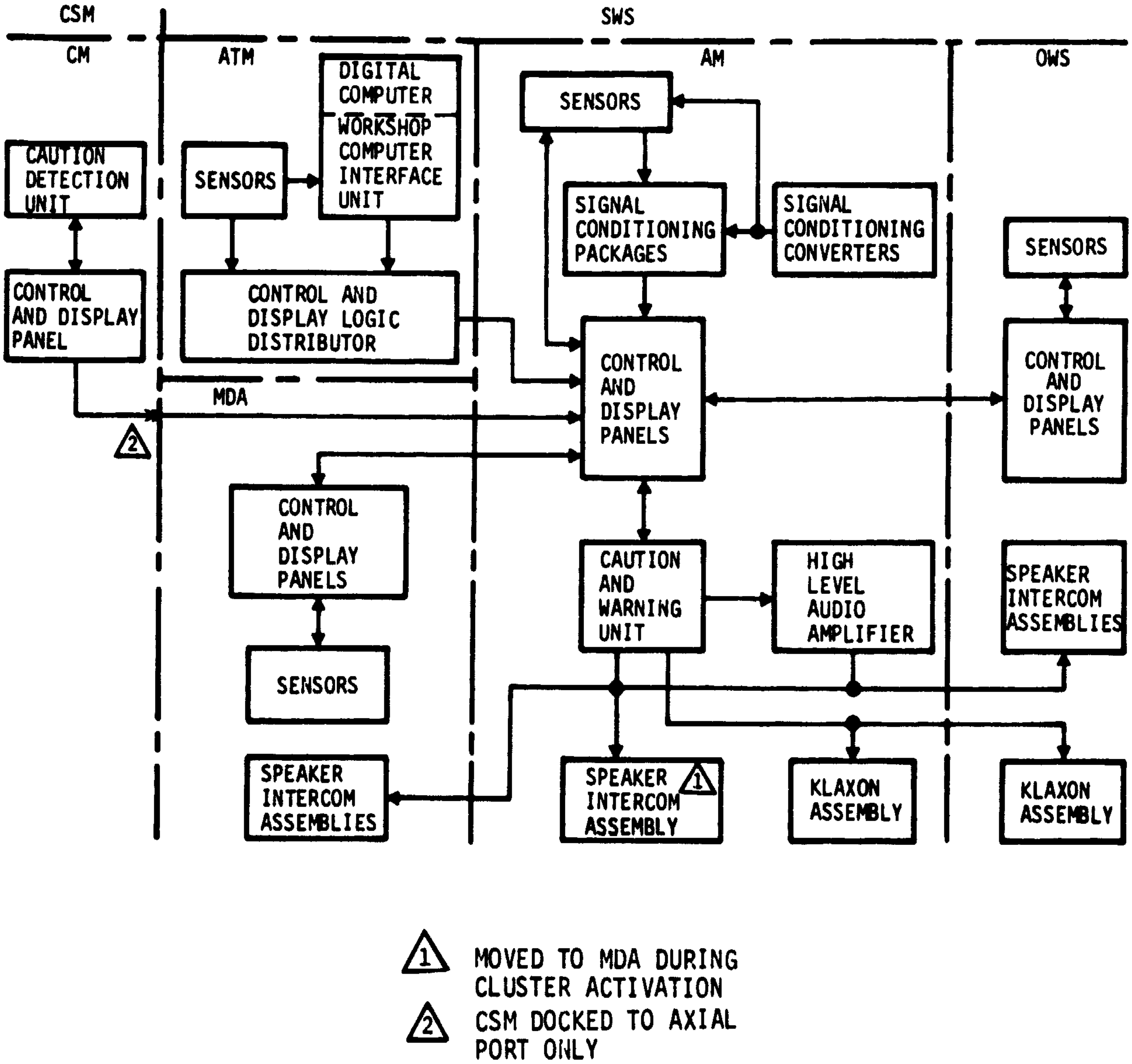


FIGURE 2.11-1 CLUSTER CAUTION AND WARNING SYSTEM

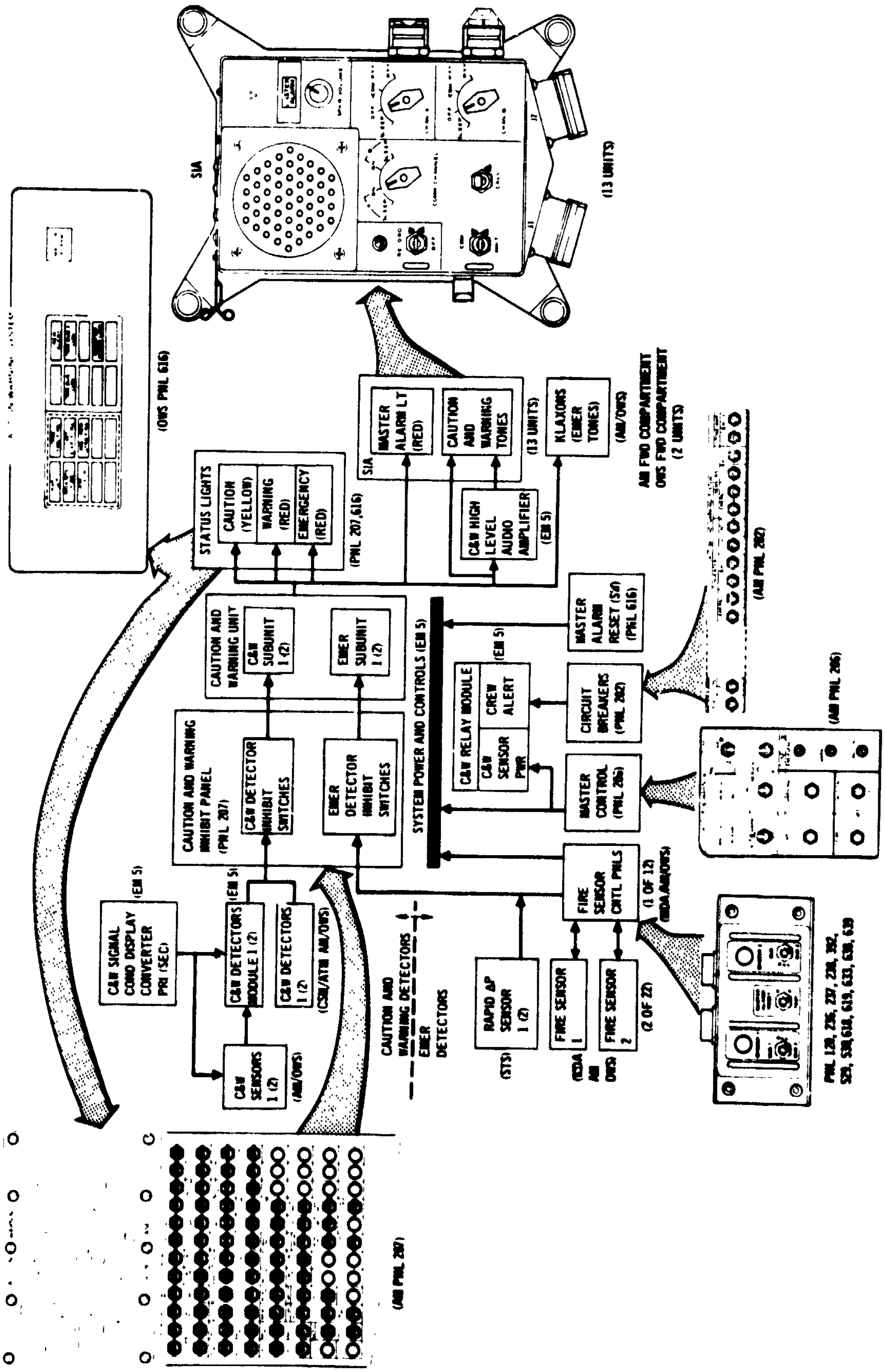


FIGURE 2.11-2 CAUTION AND WARNING SYSTEM CONTROLS AND DISPLAYS

2.11.2.2 Major SWS C&W Components

The SWS C&W System was made up of the following major components:

A. Circuit Breaker Panel 202 - Circuit Breaker Panel 202 housed the SWS C&W System related circuit breakers. This panel was located in the STS. Fourteen circuit breakers were utilized for controlling power to various components of the C&W System. These circuit breakers provided power to the redundant components within the system from two independent energized buses.

B. Control and Display Panels - A total of fifteen separate control and display (C&D) panels were provided in the SWS for control, display, operation, and testing of the caution & warning and emergency subsystems. Three of these panels were used for control and display of both subsystems; whereas, the remaining twelve were used for control and display of the fire detection portion of the emergency subsystem.

(1) Control and Display Panel 206 - The major power and control switches for the SWS C&W System were located on Panel 206 in the STS. The master alarm red telelight switch was illuminated when either a caution, warning, or emergency parameter was activated. When depressed, the master alarm telelight switch provided a reset signal to the C&W unit electronics to terminate the audio tones, extinguish all master alarm telelight switches and master alarm status lights, and remove the telemetry closures. In the emergency subsystems, this reset signal also extinguished the parameter identification lights when the parameters had returned within limits. The memory recall amber telelight switch was used to indicate that caution and/or warning parameter(s) which activated the C&W subsystem has been stored in memory. Depressing the memory recall telelight switch caused the identification light(s) to be illuminated for the parameter(s) which were stored in memory. This provided for the identity of short term C&W subsystem activations after the fact. The clear switch erased the memory circuitry in the C&W unit and extinguished the recall telelight switch. Three power switches were provided for powering the SWS C&W System. One switch was used to control power to the C&W subsystem and the other two switches were used for the emergency subsystem. Four test switches were provided for testing the C&W subsystem electronics, audio tone, and visual displays.

Three volume controls were also provided for controlling the intensity of the emergency, warning, and caution tones.

(2) Display and Inhibit Switch Panel 207 - The parameter identification lights and inhibit switches were located on Panel 207, also in the STS.

There were forty parameter identification lights used to aid the crew in identifying which parameter or system had gone out-of-tolerance. Emergency and warning parameter lights were color coded aviation red while caution parameter lights were colored aviation yellow. Each display had two bulbs for redundancy, with each bulb being driven by separate power sources.

Each parameter monitored by the C&W System had a corresponding inhibit switch(s) on Panel 207. The inhibit switches were used to disable a malfunctioning circuit or input signal without disabling other active parameter inputs. They could also be used to determine the nature of the malfunction in those cases where more than one parameter shared a common identification light. There were 76 double-pole single-throw inhibit switches utilized on this panel.

(3) OWS Repeater Panel 616 - This panel was located in the Experiment Compartment of the OWS. The panel contained one master alarm reset telelight switch (aviation red) which performed the same function as the master alarm telelight switch on AM Panel 206.

Ten parameter identification lights were utilized to aid the crew in identifying various parameters of systems that had gone out-of-tolerance. Each display contained two bulbs which were powered from separate power sources. The lights were color-coded the same as those appearing on AM Panel 207.

(4) Fire Detection Control Panels - The fire sensor control panels (Panels 120, 236, 237, 238, 392, 529, 530, 618, 619, 633, 638, and 639) provided the controls for operation and test of the fire sensor assemblies. A typical panel is shown in Figure 2.11-2.

Each panel had the capability of controlling two sensors. Two power switches were provided, one for each sensor, which allowed manual selection of one of two normally energized buses capable of supplying power to the respective sensor. A master alarm reset/test switch was provided for testing the sensor(s)

and resetting the SWS C&W System. A red display lamp was provided for each of the two sensors which illuminated upon activation of the sensor and remained illuminated until power was momentarily removed from the sensor. The bulbs and lenses on the panels and the panels themselves could be replaced inflight. Two spare panels (complete with lenses and bulbs) and eight lens and bulb assemblies, were stowed in the OWS for inflight replacement. In cases where one panel controlled only one sensor, a clip was provided for covering the unused control and display. When both sensors were energized, the panel dissipated 5.5 watts of power.

C. Caution and Warning Unit - The C&W unit contained redundant C&W subunits and redundant emergency subunits. Each subunit was powered from a normally energized bus and was protected by an independent circuit breaker. Each C&W subunit utilized 36 caution and 26 warning parameter inputs and provided 22 caution and 17 warning outputs for parameter identification lights. Each emergency subunit had 12 parameter inputs and provided 12 outputs for parameter identification lights. The capacity of the C&W unit, including growth capability, is shown in Figure 2.11-3.

INPUT TYPE	INPUT CAPACITY **					
		GATES				
	CHANNELS	SINGLE	"2 OR"	"3 OR"	"8 OR"	TOTAL
AM CAUTION	16	8 ***	5	2	1	32
*OWS CAUTION	4	4 ****	0	0	0	4
AM WARNING	11	4	2	4	1 ***	28
*OWS WARNING	1	0	1	0	0	2
OPTIONAL-AM CAUTION OR WARNING	7	2	5 ***	0	0	12
*OPTIONAL-OWS CAUTION OR WARNING	1	0	1	0	0	2
*EMERGENCY-FIRE	5	0	5	0	0	10
*EMERGENCY-PRESSURE	1	0	1	0	0	2

NOTES:

*THESE INPUT TYPES CAUSED IDENTIFICATION LIGHT OUTPUTS FOR THE OWS IN ADDITION TO THOSE ON THE AM CAUTION AND WARNING SYSTEM PANEL.

**THE QUANTITIES GIVEN ARE FOR ONE HALF ON THE CAUTION AND WARNING SYSTEM; THE SYSTEM ELECTRONICS (EXCLUDING SENSORS) WERE COMPLETELY REDUNDANT.

***ONE SPARE CHANNEL

****TWO SPARE CHANNELS

FIGURE 2.11-3 CAUTION AND WARNING SYSTEM PARAMETER INPUTS

Each subunit provided a current limited control voltage that was DC isolated from the input bus. The control voltages from the two C&W subunits were dioded together to provide one combined control voltage; whereas, the emergency subunits control voltages remained isolated. These voltages were routed to their respective C&W System parameter closures and control switches for operating the C&W System. The control voltage returns for all subunits were isolated from each other and all other vehicle returns.

The C&W unit was coldplate mounted on AM Electronics Module 5. In the standby mode, the unit consumed a maximum of 100 watts of power.

D. High Level Audio Amplifier - A high level audio amplifier (HLAA) was added to the SWS C&W System to provide caution and warning tones in the event of a failure to the buses powering the speaker intercom assemblies. The HLAA amplified the caution or warning tone from the C&W subunits and applied the tone directly to the speakers in the speaker intercom assemblies. The HLAA contained two amplifiers for redundancy; each amplifier was powered from a normally energized bus and was protected by an independent circuit breaker. The HLAA consumed ten watts of power when in the standby mode and a maximum of 100 watts when amplifying the caution and warning audio signals. The HLAA was coldplate mounted on AM Electronics Module 5.

E. Signal Conditioning Packages - Two signal conditioning packages (C&W instrumentation packages) were provided for redundancy. The signal conditioning packages conditioned preselected signals from the C&W System sensors and voltage levels from monitored buses. A total of 19 caution and 17 warning parameters were routed to the signal conditioning packages. These signals were routed into level detectors that were preset to trigger when a designated signal level was exceeded. The level detector turned on a relay driver which provided a relay closure to the C&W System. All level detectors in the signal conditioning packages except the PPO_2 low detectors received their basic power from the C&W signal conditioner converters which supplied ± 24 VDC regulated voltages to the detectors. Power for the relays and the PPO_2 low detectors were powered directly by the EPS control buses. The signal conditioning packages were coldplate mounted on AM Electronics

Module 5. The total level detector power consumption was 3.7 watts per package. In addition, each energized relay required approximately one watt of power.

F. Signal Conditioner Converters - The DC-DC converters converted the EPS bus voltage into ±24 VDC and +5 VDC regulated voltages. The ±24 voltages were used to power the level detectors in the signal conditioning packages and the differential amplifiers in the $PPCO_2$ sensors. The +5 volts were used to power the EVA suit inlet water temperature sensors and the AM coolant loop temperature sensors. Two signal conditioner converters were utilized for redundancy and were mounted on AM Electronics Module 5. Each converter consumed 11.5 watts of power.

G. ATM Digital Computer/Workshop Computer Interface Unit (ATM Provided) - The ATM digital computer provided the primary computational capability for the ATM pointing control system and the cluster attitude control system. There were redundant ATM digital computers which interfaced with the workshop computer interface unit (WCIU) within the ATM. The WCIU provided the input/output buffering and automatic switchover capability for the two digital computers. Each computer contained subroutines for determining out-of-tolerance conditions and for setting the discrete output registers in the WCIU. The discrete output registers determined the status of the relays which provided the discrete C&W closures. Each ATM digital computer weighed 100 pounds and dissipated 165 watts. The WCIU dissipated 105 watts.

H. Control and Display Logic Distributor (ATM Provided) - The control and display logic distributor housed the relays which were used to provide the C&W closures in the ATM. The combined C&W control voltages, routed via redundant paths from the ATM/AM interface to the C&D logic distributor, were applied to two control buses within the distributor. These control buses provided the C&W control voltage for the various C&W closures. The unit accepted discrete inputs for energizing the various relays and provided redundant outputs which were routed across the ATM/AM interface through separate connectors. The control and display logic distributor dissipated 40 watts of power.

I. Speaker Intercom Assemblies - Thirteen speaker intercom assemblies (SIA's) were located through the SWS for intercommunications between the crew and communications with the ground. These assemblies contained a red master alarm status light on each unit and were also used for reproducing the caution and warning tones. The caution tone was a continuous 1 kHz frequency while the warning tone was 1 kHz frequency, modulated at a 1.4 Hz rate. The C&W tones were routed to both the SIA speaker and the crewman communication umbilical connectors. In the active mode each SIA consumed 4.0 watts of power. Two flight spares were stored in the OWS for inflight replacement.

J. Klaxon Assemblies - The klaxon assemblies contained redundant speakers which converted the emergency signals into audio tones. The emergency audio tones were coded to permit the crew to readily identify the nature of the emergency situation. The fire tone was a siren while the rapid ΔP tone was a buzzer. For isolation purposes, one speaker in each klaxon assembly was driven by Emergency Subunit 1; whereas, the second speaker was driven by Subunit 2. One klaxon assembly was located in the forward tunnel of the AM and the other in the forward compartment of the OWS.

K. Sensors - Two sensors, i.e., fire and rapid ΔP, were unique to the SWS C&W System. A description of these sensors follows. The remaining sensors used by the C&W System were previously developed and are described under the Instrumentation System, Section 2.9.

(1) Fire Sensor Assembly - Detection of fire conditions aboard the SWS was accomplished by twenty-two fire sensor assemblies (FSA's) located throughout the pressurized compartments. The fire sensor assembly consisted of an ultraviolet (UV) fire detector and a quick release adapter plate which provided for easy installation and replacement. There were two FSA's located in the MDA, eight FSA's located in the STS, and twelve FSA's located in the OWS. The FSA's located in the MDA and OWS were used to provide general area coverage, whereas, those in the STS were used for viewing particular modules. Each fire sensor assembly was a self-contained unit whose operation was controlled by a fire sensor control panel (FSCP). The FSA's were designed with an optical field-of-view of

120° included cone angle. The detectors, though not totally redundant, were mounted in such a manner as to provide as much coverage overlap as possible. A fire detected by any of the FSA's would result in a generation of an emergency alarm by the C&W System. Six FSA's were stored in the OWS for flight replacement.

Fire Detector Description - The detectors monitored the UV emission from flames and provided for the initiation of an emergency alarm when the UV intensity exceeded the detector threshold level. Flames emit large amounts of photons which includes the 1800 to 2800 Å wave-length region of the UV fire sensor sensitivity range.

The detector consisted of two UV radiation sensing tubes and the associated electronics for conditioning the signals. A twin-tube approach was utilized to preclude false fire alarms with passage of the Skylab through the earth's radiation belts. One sensing tube monitored background particulates incident upon the system while a second tube monitored both the background particulates and ultraviolet radiation. The pulse rate out of each tube was conditioned by the electronics and filtered to obtain a DC voltage proportional to the pulse rate. The difference between the DC voltage representing the UV detector tube and the background tube was a measure of the UV flux emitted from a fire source. An emergency alarm was initiated when the difference in tube outputs exceeded a preselected value. A statistical analysis of the design, based on estimates of radiation levels expected to be encountered in the Skylab orbit, indicated that a threshold of 35 counts/sec and a time constant of one second would preclude more than one false alarm for each 56 day mission. To compensate for the unexpected, however, the FSA's were designed with a gain adjust having the capability to select a sensitivity setting from 25 to 75 counts/sec. Typical FSA response time to UV input equivalent to a 50 microampere standard flame at a distance of ten feet was less than one second.

The emergency alarm activated by the FSA had two forms. One was switch closure to the fire sensor control panel (FSCP), which in turn initiated a relay closure for the C&W control voltage.

which activated the C&W unit. The other emergency signal generated by the sensor provided an electrical ground for a display light located on the FSCP. Extinguishment of the fire resulted in the relay opening. The electrical ground output for the display light remained latched on after a fire was sensed and could only be reset by temporarily removing power from the sensor.

Preflight system verification tests of the fire sensor operation were accomplished during ground tests via a UV light source and the panel mounted test switches. In-flight, partial circuitry tests were performed using the FSCP test switch or the C&W system test fire switch on AM Panel 206.

Sensor Selection - Although an abundance and variety of commercial fire sensors existed, it was found that little had been accomplished toward developing space qualified devices. Devices subject to an intensive study included the following:

- Correlation spectrometer (gaseous products).
- Ultraviolet and/or infrared sensors (flame).
- Temperature sensors (heat).

The ultraviolet radiation detector was selected.

The results of the study indicated that detection of ultraviolet radiation emitted immediately following the ignition of a fire provided better overall sensitivity, response time and coverage than other type flame detectors. In addition, UV was considered the better parameter for detecting flames, primarily from background considerations, i.e., the UV radiation from the sun was determined to be less likely to trigger false alarms than the infrared radiation given off by any hot body onboard the vehicle.

(2) Rapid ΔP Sensor - Detection of rapid decompression of the Skylab pressure was performed by redundant rapid pressure loss sensors. Should the cluster pressure decrease at a rate of 0.1 PSI/minute or greater, an emergency alarm was generated. This particular pressure decay rate was selected in order to permit time for emergency action. Typically a meteorite puncture of the vehicle or a large rupture of the vehicle would be the cause of a rapid leak rate. The detectors were located behind the teleprinter paper storage container in the STS.

Sensor Description - The rapid pressure loss sensors consisted of a variable reluctance absolute pressure transducer and associated electronics. The electronics buffered the absolute pressure transducer signal to the AM telemetry system, differentiated the pressure signal to obtain a rate of pressure change for the telemetry system, and energized a relay to provide contact closures to the emergency control voltages when the pressure decay rate exceeded 0.10 PSI/minute. The trip point could be adjusted prior to installation via a potentiometer located on the side of the sensor. Application of 28 VDC via the ΔP test switch on AM Panel 206 activated a self-test mode in the detector which simulated electrically, an excessive pressure loss and allowed verification of all electronics downstream of the pressure transducer. The sensor consumed 5.6 watts of power.

Sensor Selection - The rapid pressure loss sensor design utilized was selected following an intensive investigation of available sensors. Due to rigid schedule requirements, sensing devices which required limited development effort and methods with similar application were sought. The devices and methods reviewed included:

(a) Detection of high leak rates which exceeded the makeup capability of the cabin pressure regulators using pressure switches.

(b) Detection of pressure changes across a capillary restriction utilizing a low range differential pressure transducer.

(c) Analysis of the sound spectrum associated with escaping gas as a function of orifice size, direction, pressure differential, etc.

(d) Differentiation of the output of an absolute pressure transducer referenced to cabin pressure.

The absolute pressure transducer/differentiator sensing scheme was selected primarily because of its excellent response time and its ability to directly convert rate information from cabin pressure measurements.

2.11.2.3 Telemetry

Individual discrete parameters wer provided from each subunit to enable ground control to distinguish when a caution, warning, fire or rapid delta P alarm had been generated. Analog data associated with each CWU converter voltage output was also provided. These parameters, in conjunction with the selected vehicle systems telemetry parameters were used to determine system status and to resolve system anomalies.

2.11.3 Testing

Verification of the Caution and Warning System design requirements was successfully completed during the course of the testing program. The testing phase on the flight hardware employed a comprehensive program of tests. These tests began at the component level, in-house and at vendor facilities, and continued through module interface, systems, systems interface and systems integration testing. Completion of the testing program was accomplished at the launch site.

2.11.3.1 MDAC-E Tests

A large part of the system consisted of various types of sensors supplied by outside vendors who were required to verify conformance to the contractor component Specification Control Drawings (SCD). All sensors were required to pass in-house PIA tests as documented in SEDR D3-20, the Preinstallation Acceptance Tests for the Instrumentation System.

MDAC-E manufactured equipment was also tested per SEDR D3-20. This equipment included the C&W instrumentation packages and the signal conditioner converters. The individual printed circuit card assemblies were tested prior to installation in the instrumentation packages. PIA tests on the C&W unit and high level audio amplifier were performed at the MDAC Manufacturing facility. Other subassemblies such as the parameter display panel, switch and circuit breaker panels, and associated wire bundles were subjected to manufacturing mechanical and electrical checks and inspections prior to integrated system level testing. The St. Louis system level test flow utilized to verify the performance of the C&W System is shown in Figure 2.11-4.

SYSTEMS VALIDATION
26 NOV 71 TO 7 JAN 72
SEDR D3-N70

- SYSTEMS TESTS, AM VERTICAL
  - EQUIPMENT WITH AM WIRING
  - AM VEHICLE INTERFACES WITH ATM, MDA, OWS & CSM SIMULATORS
- C&W SYSTEM EMPHASIS:
  - INPUT/OUTPUT SIGNAL HANDLING
  - SENSOR TRIP POINT LEVELS
  - COMPATIBILITY WITH OTHER SYSTEMS (AUDIO, TM, ECS, ELECTRICAL, DCS AND COOLANT)

SYSTEMS ASSURANCE
28 MAR 72 TO 16 APR 72
SEDR D3-E72

- SYSTEMS TESTS, AM/MDA MATED
  - AM/MDA INTERFACE CIRCUITS
  - AM/MDA EQUIPMENT END TO END
  - SIMULTANEOUS ALL SYSTEMS OPERATIONAL COMPATIBILITY
  - REVALIDATION OF DISCONNECTIONS
- C&W SYSTEM EMPHASIS:
  - AM/MDA FUNCTIONAL END-TO-END
  - ALL SYSTEMS EMC SUPPORT
  - PARAMETERS CROSSING INTERFACES

AM/MDA INTERFACE
8 MAY 72 TO 3 JUN 72
SEDR D3-E76

- RETEST OF AM/MDA INTERFACES AND EQUIPMENT AFTER ARRIVAL OF LATE MDA EQUIPMENT

SIMULATED FLIGHT, VOL. I
6 JUN 72 TO 20 JUN 72
SEDR D3-E75-1

- SYSTEMS OPERATION TO SIMULATE INFLIGHT MODES AND SEQUENCES
- EMC TESTS:
  - CRITICAL CIRCUIT MARGINS
  - RADIATED SUSCEPTIBILITY
  - NOISE IN RECEIVER PASSBANDS
  - BUS TRANSIENTS AND NOISE
- C&W SYSTEM EMPHASIS:
  - FUNCTIONAL COMPATIBILITY AND EMC TEST SUPPORT
  - ORBITAL ACTIVATION, MONITORING OF SYSTEMS, AND POWER DOWN

ALTITUDE CHAMBER
11 JUL 72 TO 14 JUL 72
SEDR D3-E73

- CREW AND EQUIPMENT OPERATION WITH AM/MDA AT ALTITUDE
- C&W SYSTEM EMPHASIS:
  - FUNCTIONAL CHECK BY FLIGHT CREW
  - VERIFIED PROPER OPERATION OF MONITORED SYSTEMS AT ALTITUDE
  - PROPER RESPONSES TO SIMULATOR INPUTS DURING UNMANNED RUN
  - CORRECT VISUAL AND AUDIO INDICATIONS DURING MANNED RUNS

SIMULATED FLIGHT, VOL. II
4 SEPT 72 TO 13 SEPT 72
SEDR D3-E75-2

- REPEAT OF MANNED ORBITAL MODE AND EMC TESTS AFTER RETURN OF EREP

SHIP

FIGURE 2.11-4 CAUTION AND WARNING SYSTEM TEST FLOW – MDAC-E

During systems evaluation testing, SEDR D3-N70, C&W System input/output signal handling, sensor trip point levels, and compatibility with other systems (i.e., audio, TM, ECS, EPS, DCS, and TCS) were verified. C&W interface parameters were checked during the systems assurance test, SEDR D3-E72. This test also verified AM/MDA C&W functions end-to-end and supported all AM/MDA systems in an EMC check. AM/MDA C&W interfaces were rechecked per SEDR D3-E76, after installation of MDA equipment that arrived late. Simulated flight test, SEDR D3-E75, Volume 1, permitted activation, monitoring, and power down of the C&W System in the manner planned for the mission. Further EMC checks were supported by the C&W System as a part of this test. During the altitude chamber test, SEDR D3-E73, the C&W System was checked for proper responses to simulator inputs during an unmanned run, and functionally checked for visual and audio indications at simulated altitude by the flight crew. Prior to shipment, the EREP was reinstalled, and manned orbital mode and EMC tests were repeated as a part of an abbreviated simulated flight, SEDR D3-E75, Volume II.

2.11.3.2 Problems and Solutions

MDAC-E testing of the C&W System identified the following system discrepancies.

A. Alarm Tone Variations in Frequency and Quality - The caution and warning alarm tone quality varied, became less clear, and changed in frequency during system validation. Troubleshooting indicated an intermittent condition having the effect of a short on the C&W System High Level Audio Amplifier No. 2 output. The circuit was monitored during subsequent testing. During simulated flight the tone degradation reoccurred. The C&W System High Level Audio Amplifier (S/N 100) was removed from the vehicle. A functional test was then performed which verified that the system No. 2 output was defective. Unit S/N 101 was subjected to the same functional bench test, met all requirements and was installed on the vehicle. S/N 100 was found to contain resistors having incorrect values installed in the No. 2 subsection of the amplifier. All additional units were verified to have the correct parts installed. The discrepant parts in S/N 100 were causing intermittent operation of the short circuit protection circuitry which resulted in the changes in tone amplitude and frequency.

B. Erratic Gas Flowmeter T/M Parameter - During system validation, gas flow sensor parameters F205, F209, F210 and F211 had erratic outputs and indicated below normal flow rates. Investigation of this condition indicated that the flowmeters had improper shielding. In addition, the OWS gas interchange sensor (Parameter F205) was improperly located in the duct. The RF type shielding was changed to audio shielding on all four gas flow sensors and the OWS gas interchange sensor was relocated. The C&W gas flow trip points were also lowered to further reduce the probability of false alarms.

C. Unexpected Caution and Warning Power Light - The parameter identification light illuminated when Panel 207 signal conditioner inhibit switch was placed to the enable position during system validation. Laboratory tests found that a short had developed between a component and ground on a printed circuit card assembly. A new circuit card assembly was installed and system retested.

D. Primary Coolant Low Temperature Below Specification - During system assurance, C&W System temperature parameter trip points were below specifications on the primary coolant low parameter and on the EVA 1 and EVA 2 inlet temperature low parameters. The C&W instrumentation package trip points were found to be lowered by the presence of 2 to 4 MHz noise observed between vehicle structure and the DC returns from the DC-DC converters to the instrumentation packages. The problem was successfully resolved by the addition of jumper plugs to both C&W signal conditioner (instrumentation) packages. The jumper plugs contained capacitors installed between the pins connected to structure and the DC power returns. These capacitors shorted the conducted noise.

E. Noise Perturbations on MDA Temperature Parameters - Various MDA temperature parameters experienced up to 15 counts of noise at random intervals on the T/M outputs during altitude chamber tests. Testing revealed the C&W unit internal DC-DC converters were generating the noise due to their electronic switching action. The noise was coupled into the MDA temperature parameter T/M lines in the vehicle wire bundles. Capacitors installed between the C&W telemetry output signal return lines and chassis ground and between the C&W telemetry output signal return lines and chassis ground and between the C&W subunits signal ground and

chassis significantly reduced the noise coupled into the MDA temperature parameters. Modifications were performed on all C&W units to incorporate the internal capacitors.

F. No Secondary Coolant Flow Alarm - A C&W System alarm did not occur when the secondary coolant pump A switch was placed to on during altitude chamber tests. The problem was isolated to a reed switch failure. The pump containing the defective reed switch was removed and replaced.

G. Two C&W System Alarms not Recallable from Memory - During descent from altitude, two separate C&W System alarms occurred which could not be recalled from memory to be identified. Retest and troubleshooting at ambient altitude after the run could not repeat the condition. Memory recall circuitry functioned correctly in all cases. During crew debriefing, it was stated that following the first alarm the memory clear switch had been inadvertently actuated prior to attempting memory recall. The crew believed the memory recall sequence was performed correctly after the second alarm; however, the parameter identification light did not illuminate. Since the problem could not be repeated it was categorized as an unknown condition. The problem never reoccurred during subsequent testing.

H. Rapid Delta P Alarms from RFI - The rapid delta P C&W alarm triggered at various times during simulated flight EMC tests. It was found that the rapid delta P sensors were susceptible to low frequency variations in RF field strength of VHF transmitters. False alarms occurred as a result of the sensor detecting the RF variations induced on the sensor leads. Problem resolution was accomplished by installing new wire bundles, which incorporated RF filtering and shielding, between the sensors and vehicle pressure bulkhead.

I. Secondary Coolant Temperature Low Alarm - A secondary coolant temperature low alarm occurred during simulated flight, Vol. II. The sensor was found to have a low resistance short to structure. The defective sensor was removed and replaced.

J. Lack of EVA No. 2 Pump Delta P Alarm - EVA No. 2 pump delta P C&W alarm did not occur with zero pressure on SUS loop No. 2. The problem was determined to be a defective sensor which was remaining open. The sensor was removed and replaced.

2.11.3.3 Launch Site Testing

Launch site test requirements for the C&W System were defined in Report MDC E0122, Test and Checkout Requirements Specifications and Criteria for use at KSC, and by the Skylab Integrated System Test Checkout Requirements and Specifications, Document No. TM 012-003-2H. Tests per these requirements were successfully accomplished during the system level and integrated testing performed at KSC.

One significant C&W System problem occurred during KSC testing. During the AM/MDA/CSM interface test, an inadvertent rapid delta P alarm could not be correlated with vehicle activity. The new wire bundles, mentioned in paragraph 2.11.3.2H above, had been installed. Duplication of the problem was attempted at MDAC-E. Test results confirmed that the alarm occurred due to fluctuations that existed in the rate output section of the delta P sensor. The erroneous rate output was found to be a function of internal interference in the sensor resulting from the effect of two harmonics heterodyning. The transducer oscillator and the DC-DC converter oscillator, both internal to the sensor, were generating the harmonics. The sensors were modified to synchronize the DC-DC converter oscillators. In addition, filter capacitors were added between the +28 VDC return and signal return to chassis, and a zener diode was installed between the +28 VDC input lines to prevent transients on the sensor voltage regulator inputs.

2.11.4 Mission Results

The C&W System operated nominally throughout the Skylab mission and performed all required mission functions. The system successfully monitored all seventy-six parameters and satisfactorily detected out-of-tolerance conditions. The system was operational for a total of 4011 hours. During this time, the system activated approximately 220 times.

A. Out of the 76 parameters monitored, the only false alarms which activated the C&W System were associated with the fire sensor assemblies. These false fire alarms were attributed to the following factors:

(1) High Temperature - Three false alarms occurred on day 146 shortly after C&W System activation. The source of the alarm was FSA 639-1 which was located in the OWS center sleep compartment. These alarms were attributed to the excessively high ambient temperatures (approximately 145°F) in this area. The FSA was qualified to an operating temperature of 100°F. No additional alarms occurred after the SWS returned to normal operating temperatures following the deployment of the thermal parasol.

(2) High Radiation Levels - Four false alarms occurred during passes through the South Atlantic Anomaly. Dosimeter and proton spectrometer data indicated that at the time the alarms occurred peak radiation levels were encountered. On DOY 147 and 152, two alarms were activated by the No. 1 Cooling Module Fire Sensor (392-1). No additional alarms occurred following reduction in the sensor sensitivity setting from 35 counts/sec to 45 counts/sec. On DOY 365 and 016, two Experiment Compartment Fire Sensors (619-1 and 618-1) activated, respectively. The sensitivity of these sensors was not changed and the alarms did not reoccur.

(3) Sunlight - The following false alarms were caused by solar UV radiation entering the vehicle as direct sunlight or as reflected light, i.e., the earth's albedo.

(a) During the first EVA on DOY 158, OWS cooling module FSA 392-2 activated with entry of sunlight through the opened EVA hatch. Since both OWS cooling module fire sensors are located in the compartment evacuated during EVA, the associated EVA procedures were revised to inhibit both OWS cooling module fire sensors.

(b) Two erroneous fire alarms occurred on DOY 216 and were generated by the ward room FSA 633-2. At the time of the alarm, the Skylab was passing through the South Atlantic Anomaly in a near ZLV attitude with the ward room window sunshade removed. In this configuration, the unprotected window was exposed to earth reflected UV radiation. Although the SAA radiation level also encountered at the time of the alarms was less than that observed at the time of the SL-2 alarms, i.e., approximately 0.1 vs. 0.19 Rad/Hr, the combination of both conditions was considered sufficient to have caused the alarm. No additional alarms occurred and no corrective action was considered necessary.

(c) Two additional fire alarms occurred on DOY 247. The alarms were caused by ultraviolet radiation coming through the unfiltered OWS SAL window during the UV photography experiment S073/T025.

B. During the Skylab mission, two C&W System related component failures occurred. They were:

(1) FSCP - During the SL-2 mission, one component failure was identified. Side 2 of Fire Sensor Control Panel 392, S/N 10, failed to respond to self-test and was successfully replaced with an inflight spare. The removed FSCP was retained onboard as an inflight spare for reinstallation in panel locations 530 or 619 in the OWS which used only side 1.

(2) Pump ΔP - During SUS Loop No. 1 activation on DOY 218, no C&W alarm was generated from the pump ΔP sensing circuitry. This condition confirmed the loss of the EVA LCG-1 pump ΔP sensing circuitry suspected to have failed during the SL-2 mission.

C. During the Skylab missions, the C&W System in the AM/MDA U-2 vehicle and the C&W simulation in the Skylab Test Unit (STU) were maintained in a mission support mode at MDAC-E. The Airlock U-2 Caution & Warning System configuration was identical to Airlock U-1. Special tests and operational modes were performed as required to support the resolution of problems or suspected problems on the SWS inflight. Data was plotted on all C&W System related parameters to monitor system performance and to observe parameter trends for out-of-tolerance or any erratic operation. This data primarily came from the STU/STDN facility at

St. Louis. AM/MDA U-2 and STU were used to support significant mission problems occurring during the SL-2 mission in regard to fire sensor false alarms and OWS Bus 1 and 2 low alarm.

(1) Three false alarms occurred on DOY 146 shortly after activation of the C&W System. Fire sensor assembly 639-1 located in the OWS center sleep compartment was the source of the alarms. Testing was performed at the contractor STU facility on an FSA which failed at a temperature above the qualification temperature of 100°F.

(2) An OWS Bus 1 and Bus 2 low alarm occurred when the associated CB's opened. The U-2 vehicle was utilized to perform a test to verify that both Bus 1 and Bus 2 low sense circuits functioned properly. The test was to determine the possibility of a short circuit existing between the circuits due to a wiring incompatibility. Test performance proved the C&W sense circuits performed properly and were not tied together.

2.11.5 Conclusions and Recommendations

The following conclusions and recommendations are the results of a review of the C&W System design, the adequacy of the test program associated with this system, and the performance of the C&W System during the Skylab mission.

2.11.5.1 Conclusions

The design and verification of the Skylab C&W System were proven to be effectual in that all required mission functions were performed satisfactorily. In addition to properly detecting all specified out-of-tolerance conditions, no false alarms occurred as the result of abnormal C&W System behavior or C&W System component malfunctions. The system was operational during all manned phases of the mission and successfully monitored all seventy-six preselected parameters relieving the crew to perform other assigned activities. The crew reported that the C&W system performed in an outstanding manner and that they were well pleased with all C&W System/crew interfaces; i.e., system control/inhibit switches, audio alarms, indicator lights, parameter categories, memory recall, and system reset capabilities. Out of the seventy-six parameters monitored, only the gas flow, $PPCO_2$ and CMG Sat parameters activated the C&W System an excessive number of times. The ATM CMG Sat parameter activated frequently during periods of high crew activity and/or ATM rate gyro failures while the $PPCO_2$ and gas flow alarms resulted from marginal sensing techniques utilized. Refinement in techniques to accurately measure $PPCO_2$ and gas flow are required to make these parameters more meaningful.

2.11.5.2 Recommendations

The following items were identified during system testing and/or mission support activities and are recommended to further improve the capabilities of the C&W System:

- Provide the capability to monitor the inhibit switch positions associated with the various C&W parameters via a TM data word. Continual questioning of the crews was required to determine status of the inhibit switches.

- Add TM parameter, with ground reset capability, to alert ground support personnel that a C&W alarm occurred and was reset while the vehicle was out of contact with STDN.
- Improve techniques for monitoring $PPCO_2$ and gas flow to permit meaningful surveillance of these parameters.
- Utilize high level (0-5 VDC) input signals in lieu of low level (0-20 mv) signals for better noise rejection characteristics.
- Stabilize the C&W voltage parameters by balancing the TM output circuitry.
- Impose stricter EMI requirements on component design to avoid late design changes as was experienced with the rapid delta P sensor.
- Simplify wiring by incorporating circuitry presently contained in the High Level Audio Amplifier into the Caution and Warning Unit package.
- Provide ground test capability for verifying sensors that are unavailable to monitor such as the mol sieve temperature sensors.
- On future applications, add filter networks internal to the rapid delta P sensor and C&W signal conditioner packages.

2.12 CREW STATION AND STOWAGE

The internal arrangement of crew controlled, operated, accessible equipment, and controls and displays played a significant part in the success of the Skylab mission. The many aspects of living and working in space visualized during the design phase, modified in pace with program evolution, and coordinated for consistency with other elements of the cluster, placed emphasis on the following areas:

- Equipment location versus mission use.
- In-flight maintenance.
- AM and cluster controls and displays.
- Window size, location, and protection.
- Extravehicular activity.
- Lighting requirements.
- Stowage requirements.
- Customer coordination and awareness.

2.12.1 Internal Arrangement and In-flight Maintenance Provisions

The arrangement of the equipment within the Airlock Module is shown in Figures 2.12-1 and 2.12-2. This reflects the final flight configuration and was the result of several factors, the primary one being the basic design goal progressively changed to accommodate changes in program requirements.

2.12.1.1 Basic Design Goals

The principal functional requirements for the Airlock Module were to provide:

(1) Electrical power distribution, regulation and control.

(2) Instrumentation and communication systems for internal and ground station information.

(3) A caution and warning system to alert the crew of critical conditions in the vehicle.

(4) Internal and external lighting.

(5) A controlled, livable environment for unsuited astronauts within the vehicle.

(6) Equipment cooling.

(7) Life support for suited operations internal and external to the vehicle and for transfer between these operations.

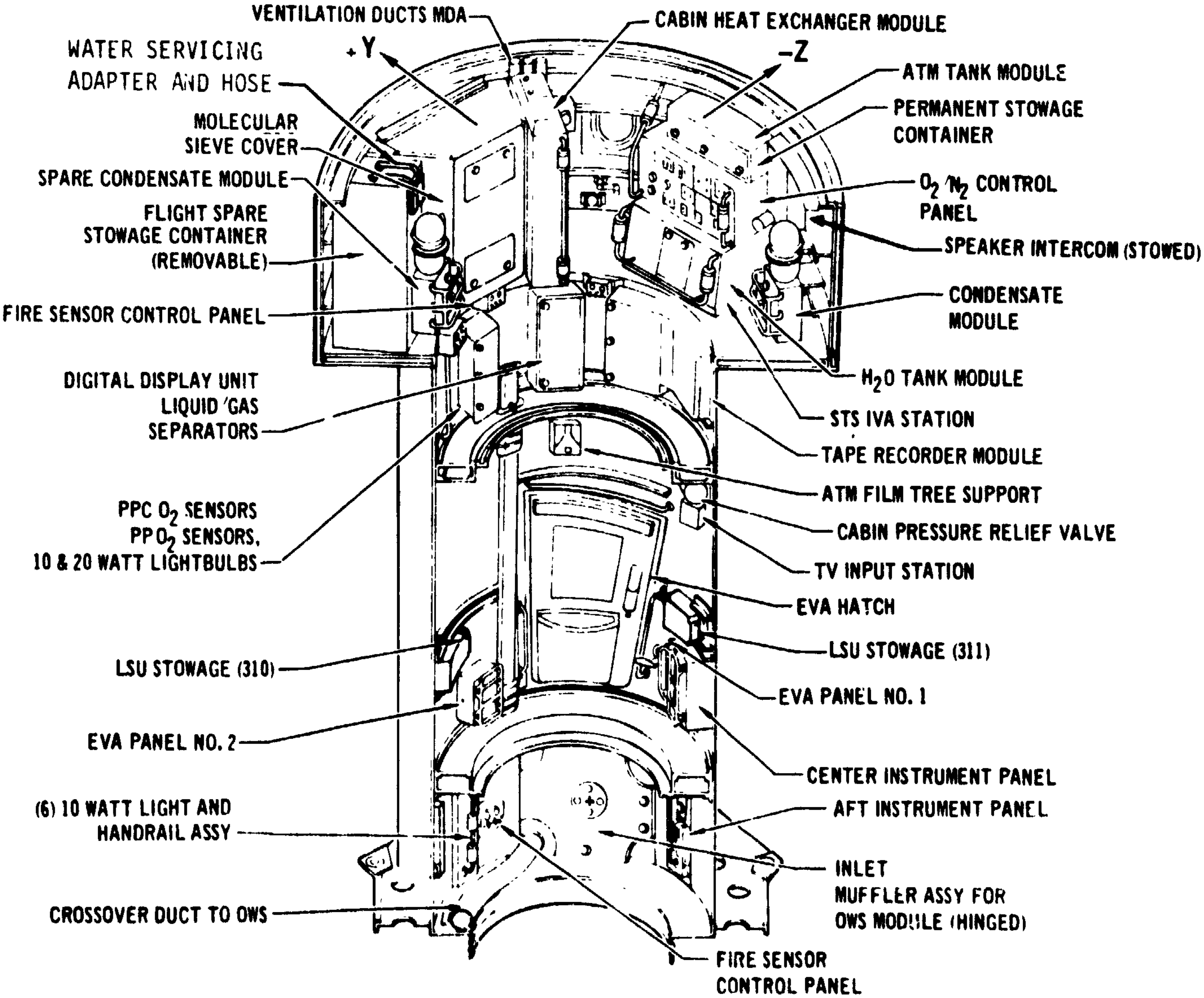


FIGURE 2.12-1 INTERNAL ARRANGEMENT (+Y, -Z)

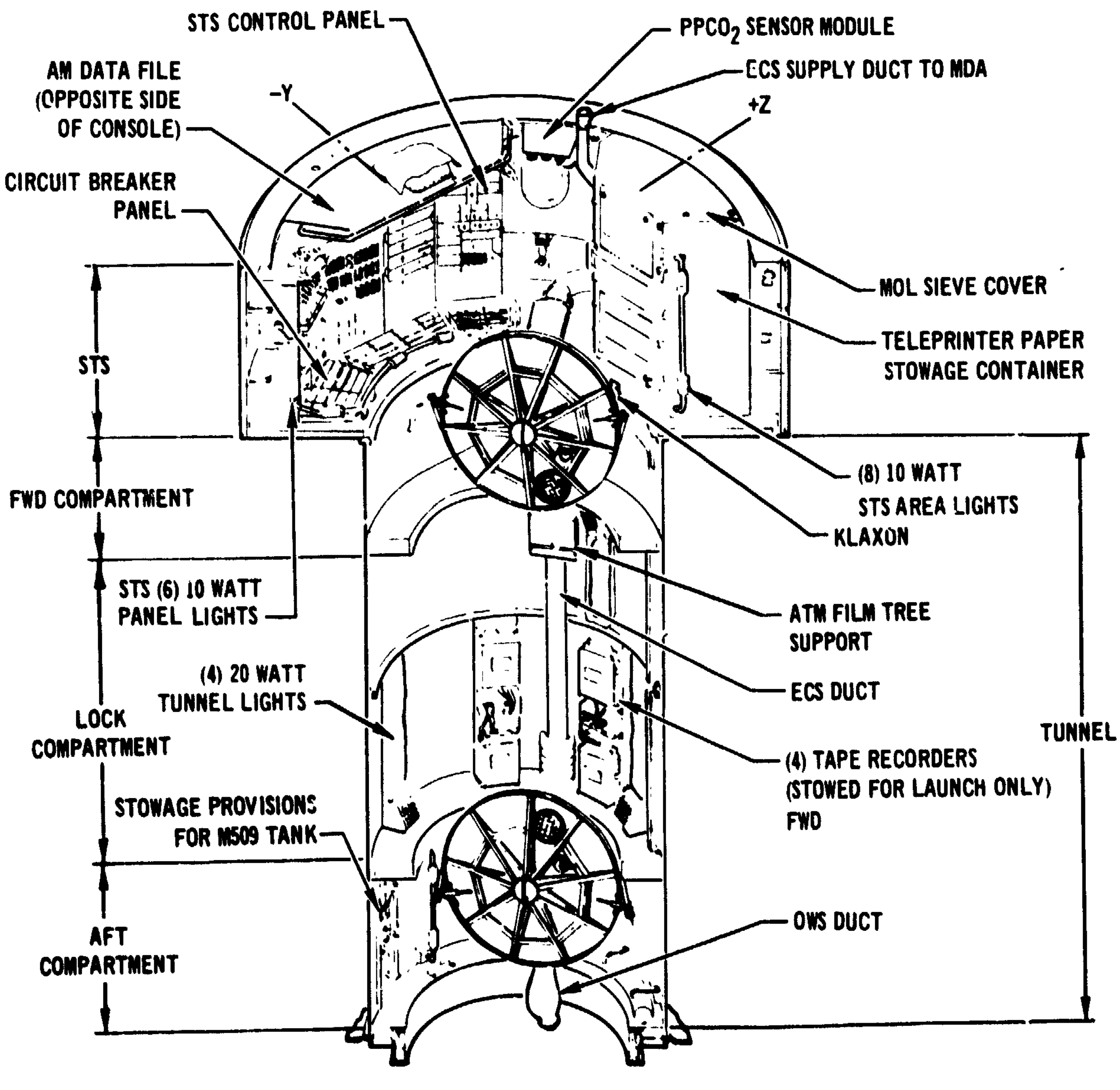


FIGURE 2.12-2 INTERNAL ARRANGEMENT (-Y, + Z)

(8) A lock to be used for egress and ingress in performance of extravehicular activites.

All the equipment shown in Figures 2.12-1 and 2.12-2 was required to fulfill these requirements. To achieve an integrated vehicle arrangement for this equipment, the following design goals were established:

- Functional and logical arrangement of equipment to facilitate usage and training.
- Circumferential arrangement to permit unrestricted translation passage throughout vehicle.
- Adequate space for crewmen to perform operations.
- Minimum wasted space and compactness to provide adequate body restraints for zero-g environment.
- Sufficient equipment envelopes to provide access for in-flight operations, including maintenance and repairs.
- Orientation and placement of controls to minimize inadvertant operation by crew.
- Adequate ventilation around equipment to preclude hot or cold spots.
- Placement of equipment to avoid excessive lengths of wiring and tubing runs, thereby increasing reliability.

The methods by which these goals were accomplished and the final results achieved were:

- o Compartmentalization of the Airlock Module.
- o Interface agreements.
- o Equipment packaging and installation orientation.
- o Extensive use of mock-ups for design and evaluation.
- o Utilization of components which would enhance simplicity of operation.

A. Compartmentalization of Airlock Module - The Airlock Module was divided into four compartments to achieve a functional arrangement of equipment; the Structural Transition Section, the forward compartment, the lock compartment, and the aft compartment. The STS was the first compartment in the AM into which the crew ingressed. Those controls required for the orbital workshop activation were therefore located in the STS. Because the systems necessary for activation included the electrical power system, the environmental control systems, the instrumentation system, the

communication system, the caution and warning system, and the lighting system, the majority of the AM systems control was located within the STS which acted as the nerve center for the Skylab. In addition to the equipment already described, the Apollo Telescope Mount reservoir module was located in the STS because of its close proximity to the ATM control panel in the Multiple Docking Adapter. Several other control panels, such as the proton spectrometer, the time reference display, and internal vehicular activities panels were also installed in the STS. The only other equipment in the STS was stowed parts to be used for in-flight maintenance and replacement of expendable supplies on the STS equipment.

The forward compartment was adjacent to the STS and used essentially as an extension for the STS. It contained a tape recorder module, a part of the instrumentation and communication system, and two stowage containers holding spares for equipment in the STS.

The lock compartment was used as an airlock for EVA operations. An internal hatch at either end of the lock compartment sealed it off from the rest of the Skylab cluster. A depressurization valve was incorporated for venting the lock compartment. A repressurization valve was located in each of the internal hatches for repressurizing the lock. Two EVA control panels were installed in the lock compartment to provide suited crew-man with life support and communication functions through their Life Support Umbilicals (LSU) which were stowed nearby. The EVA hatch provided for ingress and egress. A TV input station was located near the EVA hatch for use in monitoring EVA's. A lighting control panel for EVA and compartment lights was installed in the lock compartment. Temporary stowage devices for material retrieved during an EVA were also provided. The lock compartment contained all the equipment functionally required for performing EVA's.

The Airlock aft compartment, being adjacent to the Orbital Workshop (OWS), contained AM equipment pertinent to OWS operation such as the OWS Heat Exchanger Module, the M509 Nitrogen Recharge Station, the Condensate Dump Port and a lighting control panel for the aft compartment and OWS entry lights. In addition to providing space for this equipment, the aft

compartment was used as an extension of the lock compartment for EVA's. This usage was accomplished by closing the OWS hatch and leaving the Airlock aft internal hatch open. The decision to use this operational mode was made shortly before launch to provide more space for umbilicals and materials retrieved while Airlock was being pressurized.

B. Interface Agreements - Early in the program, interface agreements were reached which precluded equipment interference. This was particularly true of the STS/MDA interface. Since the STS had a high equipment density it was necessary that in certain areas access be provided across the interface into the MDA for inspection and maintenance functions. Close coordination with the MDA contractor and arrangement of the STS equipment was maintained to achieve this result. Another function of interface agreements with respect to equipment arrangements was the location of ducts and wiring such that protection was provided on both sides of the interface.

C. Equipment Packaging and Installation Orientation - Careful attention was given to the packaging and orientation of installed equipment modules to provide adequate access for schedule replacement items and possible in-flight repairs. Another design goal which was implemented by careful attention was the placement and protection of controls to avoid their positions being changed inadvertently as the crew translated through the vehicle; switch bar guards were used extensively for this purpose.

D. Extensive Use of Mock-ups for Design and Evaluation - Structural and equipment mock-ups were built prior to any flight equipment. These mock-ups were constantly maintained, updated and new ones manufactured throughout the program. As program requirements changed and the need for new or different equipment was generated, the new equipment was mocked up and installed on simulated vehicles. This method served as an economical proving ground for equipment arrangements and their evaluation by crew and other NASA personnel.

E. Utilization of Component Which Would Ennance Simplicity of Operation - The Airlock equipment designs used hand-operable attachments and connections wherever in-flight maintenance replaceable items were required. Most of the attachments for such items as H_2O separator plates, liquid/gas separator, ATM C&D filter, etc., were Calfax fasteners with knurled hand

knobs. In other cases for solids traps, mole sieve fans, charcoal canisters, etc., a hand-operated clamping or hold-down method was used for attachment. All disconnects required by in-flight maintenance were also designed for rapid, simple, hand operation. Self-sealing quick disconnects (QD's) were used for gas and liquid connectors. Where required, these connections were equipped with mechanical aids to facilitate their operation. In-flight maintenance was appreciably simplified by use of these components. Equipment arrangements could be made more compact because large tool access volumes were not required.

2.12.1.2 Flight Crew and NASA Interface

Integration of the Airlock design with flight crews and NASA was accomplished by the following coordination methods.

- Crew Meetings - Biweekly crew meetings were held with flight crew members and MSFC representatives during the design and development phase. These informal meetings kept the crew abreast of system design status and coordinated crew station and related crew interface items.
- Trainer Walk-throughs - Several walk-throughs of the One-G trainer were held allowing the NASA flight crews to review existing Airlock design. From these walk-throughs many design changes were made to further enhance Airlock design.
- Progressive Crew Station Reviews (PCSR) - Monthly progressive crew station reviews were held during Airlock development up to the Critical Design Review (CDR). Incorporation of over one hundred action items assigned by NASA during these reviews contributed to the highly successful July 1970 crew systems review and the CDR.
- Crew Test Participation - Flight crew participation in U-1 system verification testing, altitude chamber test and hardware bench reviews helped familiarize the crew with Airlock systems operation and associated hardware. In addition the crew witnessed or participated in many subsystem development tests such as; C&W Tones, Teleprinter Operation, Condensate Tank Dump, Water Separator Plate Wetting, LSU Servicing, DA Deployment, etc.
- Design of the Crew Systems hardware was controlled in part by several documents: The Airlock Performance/Configuration Specification, MDC Report E946; Man/System Design Requirements, 10M32158, Revision B;

and Cluster Requirements Specification, No. RS003M00003, Appendix G. Many differences existed between requirements in these documents. Several control documentation comparison studies, plus NASA coordination was required to resolve these differences and define the crew system configuration.

- Operating Procedures - During crew station design development and system/hardware evaluation preliminary operating procedures were written by MDAC crew station personnel. These procedures were coordinated with engineering disciplines and evaluated by the flight crews during the growth of Skylab. Eventually the procedures became the foundation for the crew operating procedures in the Skylab Operations Handbook (SLOH) which took the final form of the crew checklist.

2.12.1.3 Evolution

The original Airlock Module was designed for a single launch and a single 28-day mission. The final configuration, launched separately as a ready-to-use workshop, provided the same basic functions as the original concept, however the program philosophies, requirements, and hardware were considerably altered. The change from a single to a dual launch resulted in three significant configuration:

- Docking the CSM required addition of the MDA and STS to the AM.
- A solar array power generation system was added, resulting in the AM EPS batteries, chargers, and regulators.
- The LM/ATM was launched with the LM for a separate, unmanned launch.

Resulting changes to the AM equipment arrangement included moving much of the OWS stowage to the MDA and enlargement of the AM EPS control panel area, which in turn caused other panels to be moved to the STS.

The next major program change was from a "wet" workshop to a "dry" one. This deleted the requirement for much of the OWS stowage area in the Airlock. At the same time, the ATM Module was added to the SWS launch configuration, and DA power/control and ATM power/control/cooling requirements were added to the Airlock while the workshop attitude controls and passivation controls were deleted.

The final significant program change which affected the AM equipment arrangement and in-flight maintenance requirements was the replacement of the LiOH air purification system by the molecular sieves and charcoal canisters. Originally there was only one mole sieve, but this was later changed to a redundant system requiring two. Since the functions of the mole sieves, charcoal canisters, and condensing heat exchangers were closely related, it was logical and economical to incorporate them together into one unit. The volume of the units dictated that they be installed in the STS. Because this hardware represented a good portion of the ECS, the decision was made to move the ECS control panel, the condensate module, and the cabin heat exchanger from the aft compartment to the STS. Thus, program changes in system requirements and hardware caused changes in the AM equipment arrangement.

2.12.1.4 Flight Results

Crew reports indicated that the AM equipment arrangement and in-flight maintenance provisions were satisfactory both functionally and for crew usage. The SL-2 crew made special mention that they liked:

- Radial arrangement of equipment in STS.
- Size of lock compartment and equipment arrangement for EVA preparation and operation.

During each mission some circuit breakers were inadvertently tripped by the crew as they translated through the vehicle. However, after they had become more familiar with their surroundings, they were generally able to avoid these controls. The crews also reported that some of the switches on the control panels were too crowded which, coupled with parallax, caused an occasional mistake in switching. Another discrepancy which the crews made note of was that the crewman operating the ATM control panel in the MDA was often located such that he interferred with operations in the STS and with translation through the vehicle. The limited number of adverse comments made by the crew with regard to equipment arrangement and in-flight maintenance provisions in the AM indicated these items were more than adequate.

2.12.1.5 Recommendations

Since the AM equipment arrangement and in-flight maintenance provisions proved so satisfactory for the Skylab Program it is recommended that the basic design goals established for them be followed for future manned space programs. In areas where discrepancies were mentioned by the crew, it is recommended that additional design guidelines be established to avert these problems.

One such area is the use of toggle circuit breakers. A method to avoid inadvertent tripping of these devices would be to provide a positive-locked position, such as a push-pull circuit breaker. Another solution would be to provide a better means of physical protection, such as a removable cover or higher and denser switch bar guards. Still another method would be the use of solid state circuit breakers. Because each of these methods has its own disadvantages, the final choice would depend upon specific application and other design trade offs.

The crowding of controls on panels is generally due to the amount of space available and the number of switches required. This is usually compounded by changes that take place during the life of a program.

For future programs it is recommended that a single standard controls and displays/crew systems document be used as a design guideline by all contractors. There were too many control documents on Skylab resulting in several crew station inconsistencies between modules. Monthly crew station reviews were very beneficial and should be continued on future programs. Flight crew personnel requests resulted in numerous changes to controls and displays (mechanizations, nomenclature, etc.). To prevent unncessary changes on future programs, MDAC-E recommends the use of meeting minutes signed off by contractor, crew station, and flight crew representatives, to control the crew station configuration.

2.12.2 Controls and Displays

Airlock Module Controls and Displays (C&D) had their origin in the Mercury and Gemini programs. The initial 1966 proposal for SSESM used Gemini proven concepts and hardware as the baseline for application to long term space flight missions.

The specific evolution of AM controls and displays was one of continuous changes that resulted from revisions of mission requirements and launch vehicles. This evolutionary phase, though continuous, can be summarized as to C&D effects in three increments:

- All controls and displays contained in the Airlock tunnel (1966 through mid-1967).
- Multiple launches changed the configuration and moved existing controls and displays, and added new ones (mid-1967 through mid-1969).
- Configuration changed from "wet" to "dry," again moved existing controls and displays, and added new ones (mid-1969 through launch).

Individual control panel changes were a direct function of system revisions and were constantly monitored by crew reviews. The control and displays general configuration was approximately 80% finalized after the July 1970 CDR.

2.12.2.1 Design Criteria and Objectives

The criteria used for AM C&D design were derived primarily from experience in previous programs as applied to long term space flight missions.

MSFC-STD 267A was used as a guide for human factors elements of C&D design. Periodic crew reviews evaluated design progress on a current week to week basis.

The general design criteria considered for controls and displays included:

- Functional grouping.
- Pressure suited operation.
- Legibility of nomenclature/scales/dials.
- Elimination of ambiguous nomenclature.
- Relationship between controls and reaction points for zero-g operation.

- Parallax of meter type displays.
- Relation between controls and their indicators/meters and adjustments.
- Tactile feedback of control position.
- Visual indication of control position.
- Color coding of control and functions.

Objectives of C&D design effort were to provide easily operated, non-ambiguous, reliable controls and displays mechanized to insure adequate on-board crew command of all systems.

2.12.2.2 Panel Arrangement

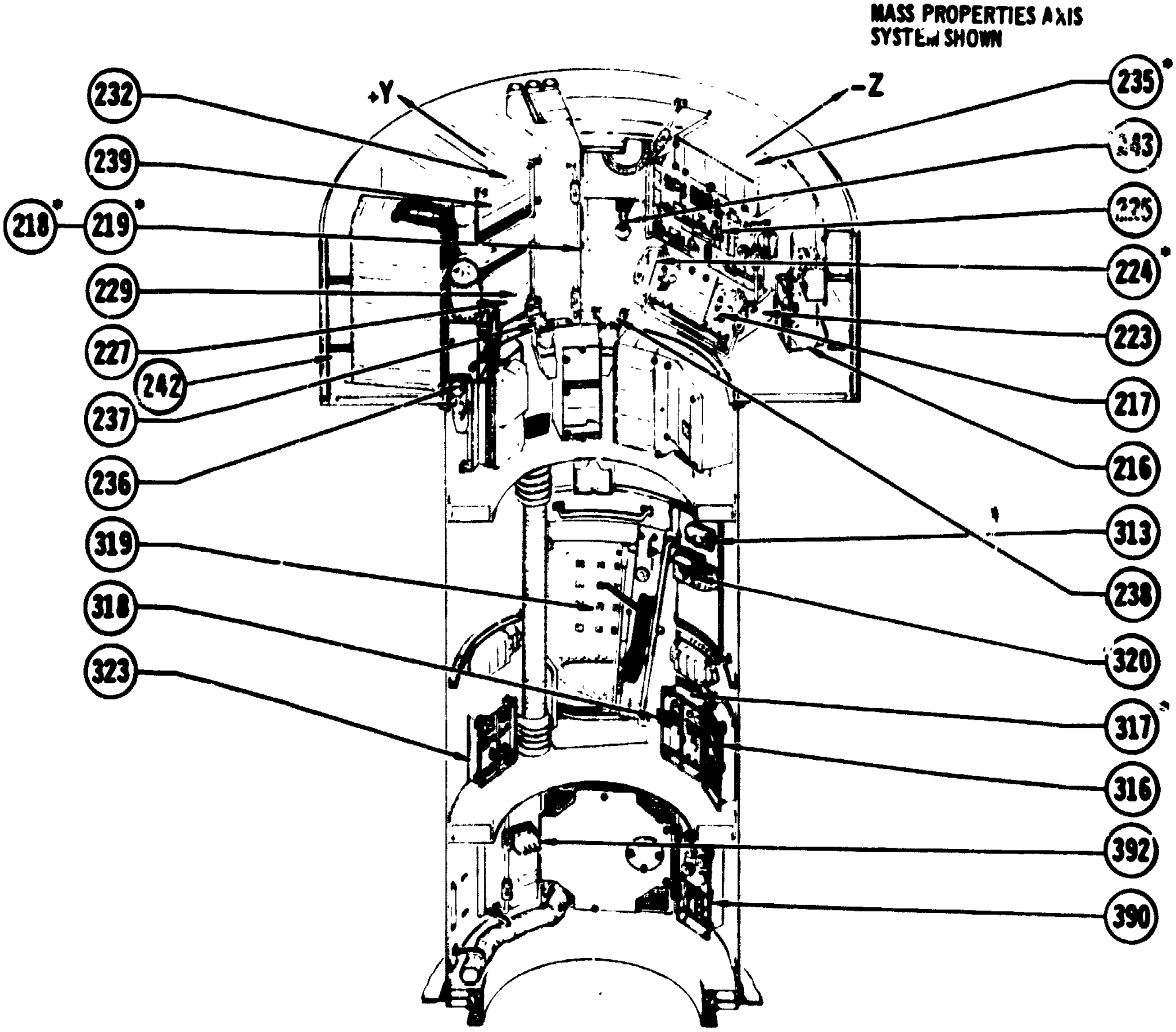
The location of Airlock Module control panels is shown in Figures 2.12-3 and 2.12-4. Figure 2.12-5 defines each specific panel (individual panel arrangements are included in Appendix A.

Controls and displays for most systems were located in the STS. Those controls and displays related to EVA and activation were located in the tunnel, except for Panel 390 in the aft tunnel. Panel 390 had critical cluster activation functions in the "wet" workshop version of Skylab and was not relocated in the change to the "dry" configuration.

Sequential reference numbers were assigned to the panels in AM. All panels in the STS are 2XX series. Control panels in the AM tunnel are 3XX series.

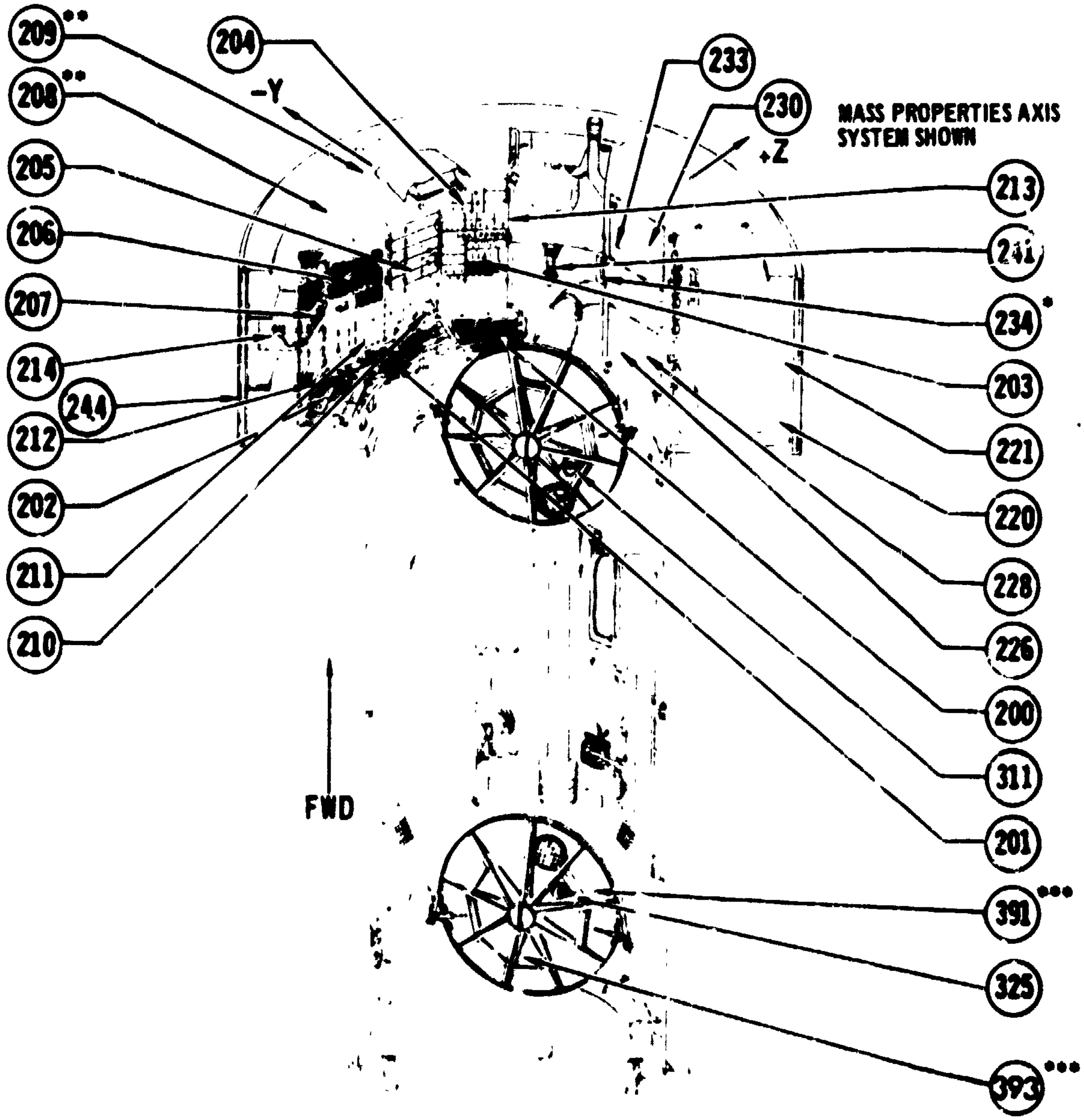
Systems considered critical and requiring periodic crew attention were grouped together in a main instrument panel location on the -Y axis. A photograph of this panel is shown in Figure 2.12-6. This group was subdivided into individual panels by system.

EPS Control Panels 205 and 206 were arranged to provide instant visual status of the EPS. Indicator lights, amber for one position and green for the alternate position, were directly above and below each momentary control switch. A momentary power system lights test switch (Panel 206) provided a quick check for nonfunctional indicator lights. Individual EPS function controls were grouped in one horizontal row, numbered left to right, one through eight. This arrangement



•PANELS 218 AND 219 ARE LOCATED ADJACENT CABIN HT EXCHRS
•PANEL 224 IS ON SIDE OF IVA PANEL
•PANEL 235 IS BEHIND STOWAGE BOX
•PANEL 317 IS LOCATED ADJACENT INSTRUMENT PANEL

FIGURE 2.12-3 PANEL LOCATIONS (+Y, -Z)



* 234 IS ADJACENT MOL SIEVE A

** PANELS 208 AND 209 ARE LOCATED ON CONSOLE

*** 391 & 393 ARE LOCATED BEHIND AFT HATCH

FIGURE 2.12-4 PANEL LOCATIONS (-Y, + Z)

PANEL NO.	NOMENCLATURE	APPENDIX PAGE
200	CIRCUIT BREAKER PANEL (ECS, I&C)	A-5
201	CIRCUIT BREAKER PANEL (EPS)	A-5
202	CIRCUIT BREAKER PANEL (EXP, LTG, EVA, TACS, C&W, SEQ)	A-6
203	CONTROL PANEL (ECS)	A-7
204	CONTROL PANEL (I&C)	A-7
205	CONTROL PANEL (EPS)	A-8
206	CONTROL PANEL (EPS, C&W)	A-9
207	CONTROL PANEL (LIGHTING, C&W)	A-10
208	CONTROL PANEL (PROTON SPECTROMETER)	A-11
209	CONTROL PANEL (TELEPRINTER)	A-11
210	PCG CONTROL SCHEMATIC	A-12
211	BUS DISTRIBUTION SCHEMATIC	A-12
212	GMT CLOCK	A-12
213	UTILITY POWER 1 OUTLET	A-12
214	UTILITY POWER 2 OUTLET	A-12
216	CONTROL PANEL (CONDENSATE)	A-13
217	CONTROL PANEL (IVA)	A-13
218	MOL SIEVE B VENT VALVE	A-13
219	UTILITY POWER OUTLET 3, (MOL SIEVE B BED CYCLE N_2 SUPPLY VALVE)	A-13
220	MOLE SIEVE A VENT VALVE	A-13
221	UTILITY POWER OUTLET 4, (MOL SIEVE A BED CYCLE N_2 SUPPLY VALVE)	A-13
223	SYSTEM 1 LCG RESERVOIR PRESS VALVES	A-13
224	SYSTEM 2 LCG RESERVOIR PRESS VALVES	A-13
225	O_2/N_2 CONTROL SYSTEM PANEL	A-14
226	MOLECULAR SIEVE A VALVE CONTROL	A-15
227	MOLECULAR SIEVE B VALVE CONTROL	A-15
228	MOLECULAR SIEVE A ADSORB/DESORB VALVE	A-15
229	MOLECULAR SIEVE B ADSORB/DESORB VALVE	A-15
230	MOLECULAR SIEVE A HEAT EXCHANGE, VALVES PANEL	A-16

PANEL NO.	NOMENCLATURE	APPENDIX PAGE
232	MOLECULAR SIEVE B HEAT EXCHANGE, VALVES PANEL	A-16
233	MOLECULAR SIEVE A AIRFLOW VALVE PANEL	A-16
234	MDA/OWS AIR SELECTOR VALVE	A-16
235	ATM COOLANT RESERVOIR PRESS VALVE	A-16
236	FIRE SENSOR CONTROL PANEL	A-16
237	FIRE SENSOR CONTROL PANEL	A-16
238	FIRE SENSOR CONTROL PANEL	A-16
239	MOLECULAR SIEVE B AIRFLOW VALVE PANEL	A-16
241	STS WINDOW CRANK -Z	A-16
242	STS WINDOW CRANK -Y	A-16
243	STS WINDOW CRANK +Z	A-16
244	STS WINDOW CRANK +Y	A-16
300	FORWARD COMPARTMENT PRESSURE RELIEF VALVE	A-17
303	HX PLATE SERVICING	A-17
311	FORWARD HATCH PRESSURE EQUALIZATION VALVE	A-17
312	FORWARD HATCH HANDLE	A-17
313	LOCK COMPARTMENT PRESSURE RELIEF VALVE	A-17
316	CONTROL PANEL (EVA SUPPORT)	A-18
317	CONTROL PANEL (EVA NO. 1 SUIT UMBILICAL SYSTEMS)	A-18
318	LOCK DEPRESSURIZATION VALVE	A-17
319	EVA HATCH	A-19
320	TV STATION	A-19
321	CONTROL PANEL (EXTENDIBLE BOOM)	A-19
323	CONTROL PANEL (EVA NO. 2 SUIT UMBILICAL SYSTEMS)	A-19
325	AFT HATCH	A-17
326	AFT HATCH HANDLE	A-17
390	CONTROL PANEL (M509 BOTTLE RECHARGE)	A-20
391	AFT COMPARTMENT PRESSURE RELIEF VALVE	A-17
392	FIRE SENSOR CONTROL PANEL	A-16
393	CONDENSATE DUMP PORT	A-20

FIGURE 2.12-5 CONTROL AND DISPLAY PANEL REFERENCES

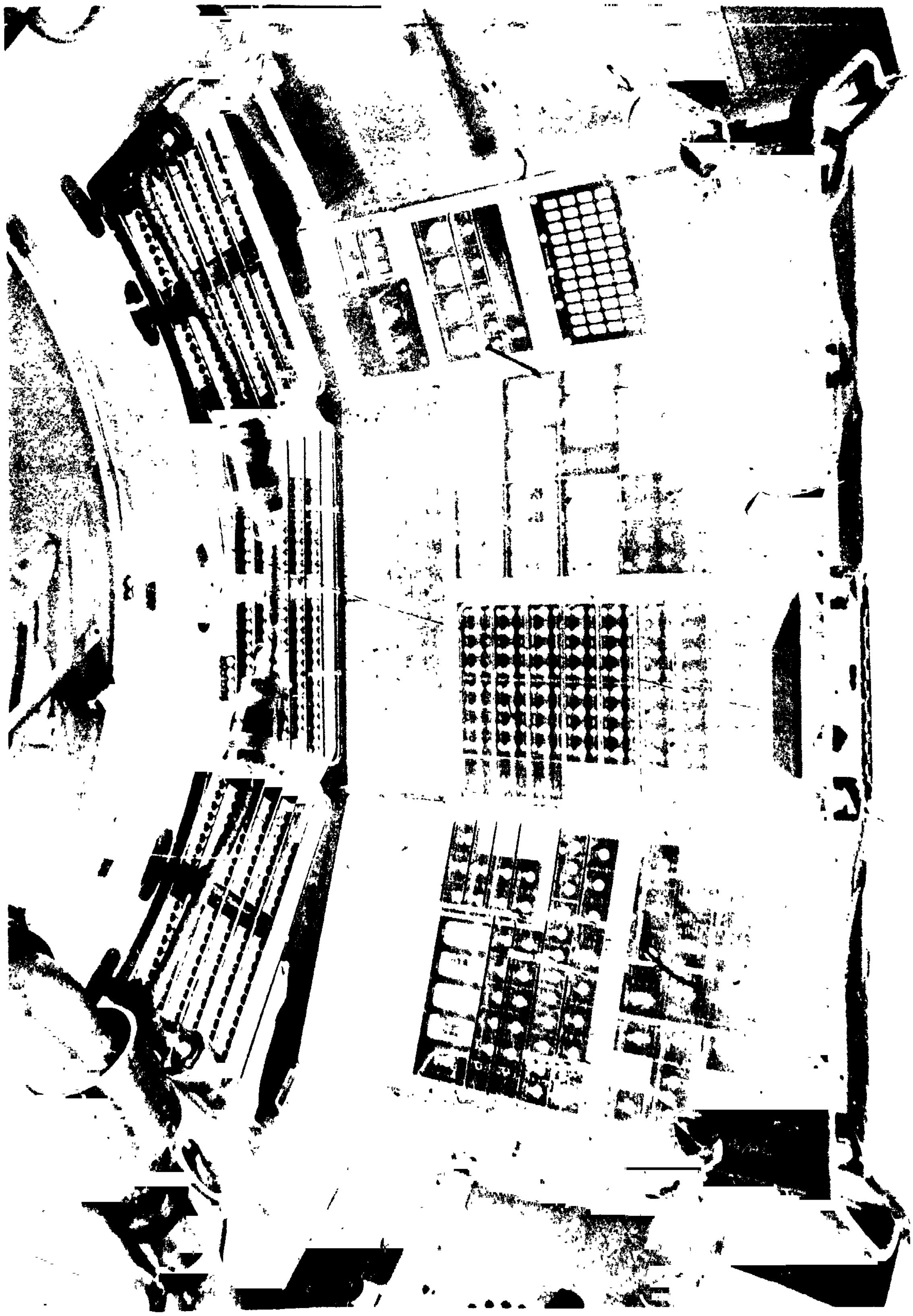


FIGURE 2.12-6 MAIN INSTRUMENT PANEL

allowed rapid scanning for status by function (horizontal) or by control group number (vertical).

All circuit breakers for power distribution (Panels 200, 201, 202) were positioned on AMS 157 bulkhead with wiring external to the vehicle. Bar guards were positioned over the breakers to provide operating reaction points and prevent inadvertent operation while permitting visual indication of breaker position. The panels were arranged to segregate the breakers by function, with main power distribution breakers on Panel 201. Panel 200 breakers consisted of two general groups; the right hand side included breakers for instrumentation, audio, data recording, telemetry, command systems, and time reference system, all directly related to data keeping. The left hand side of Panel 200 contained breakers for ECS and TCS. Panel 202 contained breakers less directly interrelated. The breakers were grouped by function, with EREP, EVA, lighting and experiments on the left side. TACS, C&W, TV, power outlets, Deployment Assembly, and sequential events breakers were on the right side.

Color coded bands beneath the breakers were used to denote the Bus from which a circuit breaker derived its power. This color code was also depicted in the Bus Distribution Schematic on Panel 211 for quick crew reference. Redundant power distribution was indicated in the color code bands by diagonal black stripes across the band width.

All AM controls were mechanized to provide a crew override capability and indications of control position and system status.

Control mechanization was indicated by schematic diagrams superimposed directly on control panels where critical systems were involved and panel space allowed (e.g., O_2/N_2 Control Panel 225, and the M509 Bottle Recharge Panel 390). Where panel space was insufficient or controls seldom used, schematic diagrams were imprinted on adjoining panels (e.g., LCG Cooling Loop schematic inside access door on panel 217, the Condensate Control Panel 216, and Mole Sieve Valve Control Panel 226). Positive indication of all control positions was achieved by utilizing detents, pointers, and switch bat handles to show operating positions and modes. Indicator lights were used to present system selections made by momentary switches.

Controls (valves, QD's, connectors) that required unusual manipulation to operate or had self-locking features to prevent accidental operation were clearly marked with operation instructions (e.g., "pull to turn" on Forward Compartment Pressure Relief Valve Panel 300).

Meters were developed specifically for Skylab, with no commonality to Gemini or Mercury hardware. A special universal indicator (meter) was designed with total systems requirements considered. This approach produced a meter movement common to all displays, that interfaced with many different systems and transducers, requiring only a change in scale and internal resistance. Each meter case housed two displays which greatly reduced panel space requirements. The meters were edge reading and had a stepped scale which located needle and scale markings in the same plane to eliminate parallax. Scales were translucent white with black numbers and internally lighted with redundant 28V bulbs. Meters were easily readable with ambient external lighting.

The meter cases were front or rear panel mounted with an electrical connector interface which eliminated solder connections and screw terminals and allowed quick meter changeout during vehicle assembly and checkout. The meters were hermetically sealed with an external zero adjust.

The glass face over the scale was protected with flame retardant lexan for shatter protection. Meter design allowed hard mounting. Where panel space permitted or system mechanization dictated, meters were located directly above controls or adjustments related to them (e.g., ECS Control Panel 203, EPS Control Panel 206, and O_2/N_2 Control Panel 225).

Nomenclature selected to prescribe control and display panel functions used 3/8", 3/16" or 1/8" high lettering of sans-serif gather style. All lettering, with the exception of the mole sieves, was black on a white or gray background.

The larger letter heights were used for identification of whole panel assemblies and groups of related controls. The smaller letters were used for individual control positions.

Abbreviations and acronyms used were consistent throughout AM control panels.

Semantics of the nomenclature was carefully examined to eliminate ambiguity and to provide an indication of control function mechanization (e.g., circuit breakers providing power to control relays were identified with the word "control," while circuit breakers that provided power directly to a system eliminated "control" from their identification).

Color coding was provided on selected controls within the AM for specific purposes. First, cautionary: a black and yellow stripe denoted a control that should be used with caution and adequate preparation (e.g., lock compartment depressurization valve). Second, Emergency: aviation red indicated emergency type crew interface (e.g., fire extinguisher ports). Third: items discarded on activation were painted green. Fourth: a variety of anodized aluminum decals and markers were used to emphasize critical crew interfaces and provide easy visual identification of similar connectors whose functions were not interchangeable (e.g., SUS water inlet QD was blue anodize, mechanically identical SUS water outlet QD was red anodize). While not actually a color code, black or white stripes were used on all crew operated electrical connectors to denote major keyway location.

Special tools required for crew control operation were located and tethered directly adjacent to the control that required the tool (e.g., regulator control fine adjustment potentiometers, Panel 206).

2.12.2.3 Flight Results

Flight crew debriefings indicate that the Airlock controls and displays proved more than adequate. Inadvertent control operation did occur, but the guards provided kept this accidental operation to a minimum and no critical circuits were activated. Only one SIA switch may have been broken as a result of crew activity. These results would indicate that acceptable design, construction, and checkout were achieved.

2.12.2.4 Conclusions and Recommendations

The flight results of Skylab proved the MDAC-E approach to Airlock Controls and displays. As expected, for the first vehicle designed for long manned duration, many lessons were learned. Many improvements were made during checkout of the Airlock, while other improvements were suggested as a result of the mission. However, the basic design, layout and groupings of the Airlock controls and displays adequately met all mission requirements. In considering future manned vehicles, special attention should be placed on the following areas:

- Functional shape of controls.
- Protection from accidental operation.
- Specific and general groupings per function.
- Meaningful nomenclature and consistency with other vehicle elements.
- Legibility of lettering in regard to both size and font style.
- Readability from wide viewing angles.
- Protection of lettering from wear.
- Flexibility in regard to addition, deletions, and moving of controls and displays during program development.
- Direct and frequent interchange of information between designers and flight crews should be emphasized.
- Design aids, mock-ups, trainers and simulators are necessities for evaluation and design verification of controls and displays.

2.12.3 Visibility

Two means of visibility were provided in the Airlock Module: (1) the STS windows were used for viewing the exterior of the vehicle, and (2) the internal hatch windows were used for viewing between compartments when the hatches are installed.

2.12.3.1 STS Windows

The STS windows were designed into the compartment pressure wall to provide the crew with a means of looking outside of the vehicle. Four STS windows were located along the midline of the compartment at 90° intervals. Each window was oval in shape with a length of 12 inches and width of 8 inches. The number, size, shape and location of these windows was consistent with structural and thermal design considerations.

The primary safety hazard to consider with the STS windows was breakage. Several design methods were employed to minimize this possibility. A dual pane concept was used such that if one pane were cracked or broken, the other would maintain a pressure seal. One disadvantage presented by this design was the possibility of fogging between the panes. To avoid this, the windows were purged with nitrogen and sealed during manufacture. Prior to launch, a manual valve in each window was opened to allow them to vent during launch and orbital insertion; this valve was then closed during initial activation. There were no reports of interpane fogging during flight.

The second method used for the protection against breakage was the use of a high strength, tempered glass inner pane. Testing of this glass showed it to be highly resistant to shattering. The third and final method used to prevent the windows from being broken was a retractable cover which could be located over the outside of the windows. These covers were crank operated from the inside of the vehicle and primarily provided protection from meteoroids. They were also used to shut out external light during sleep periods and to minimize heat losses.

A second safety consideration was the admittance of infrared radiation through the STS windows. Such introduction could cause heating of the inner pane, resulting in a touch temperature problem and/or condensation forming on the inner pane. A fine gold coating was deposited on the inside surface of the outer pane to reduce IR transmission.

The third safety consideration was to prevent ultraviolet rays from entering the vehicle and triggering the Fire Sensor Units in the AM. A UV coating was placed on the outside surface of the inner pane to filter the UV from the light entering the vehicle and thus avoid fire sensor problems.

2.12.3.2 Internal Hatch Windows

Windows were placed in the internal hatches to provide viewing between compartments when the hatches were closed. Each internal hatch contained one window in line with each other in the +Y, -Z quadrant. The windows were round ports 8.5 inches in diameter. The only hazard considered for the internal hatch windows was breakage. The window design incorporated three methods to preclude this:

dual pane redundancy, the use of high strength tempered glass for both panes, and a stainless steel grid over both sides of the window.

2.12.3.3 EVA Hatch Window

The Gemini hatch used for EVA egress and ingress incorporated a viewing window in the initial design. This window served no functional purpose in the Airlock, however it was retained to eliminate making a design change. As an additional safety consideration it was covered with a semitransparent teflon tape prior to launch and a velcro attached metal cover was installed over the inner pane during SL-2 activation.

2.12.3.4 Flight Results

The STS windows were used as expected during the mission. The internal crewman observed EVA crewmen through the STS window located toward the EVA area, and monitored the EVA tasks being performed. Television coverage of the parasol and Solar Array System deployments performed during the first mission was made through the STS windows. Visual correlations of vehicle attitudes were made through the windows, as were inspections of the external vehicle surfaces and structures; i.e., the differences in surface color changes between shaded and unshaded surfaces were noted in this manner. The windows also provided natural lighting within the vehicle.

The three crews were very pleased with the utility of the STS windows and stated a desire for more and larger windows in the cluster. Better visibility for external viewing and photography, and better external observation of the vehicle would have been beneficial. They also commented that the rolling of the ATM canister could be easily observed through these ports. One crewman observed "lint" on the outside of the windows, the others had not made this observation. This might have been some shredding from the retractable window cover. The cover on STS Window Assembly 243 would not close completely by the end of the first mission, but still provided protection for the entire window. At times the inside window surface on the dark side of the vehicle fogged up when the cover was open. This condensation cleared up when the cover was closed. The windows were closed during sleep periods to prevent the light from illuminating the whole vehicle.

The Airlock Module was launched with both internal hatches closed. The first flight use of the internal hatch windows was during initial activation when the EVA hatch was visually inspected through the forward internal hatch window prior to entering the Lock Compartment. At that time, it was noted that visibility of the Lock Compartment and the EVA hatch was very good. The forward internal hatch window provided observation of the EVA crewman in the Lock Compartment prior to egress and after ingress.

2.12.3.5 Conclusions and Recommendations

STS and internal hatch windows proved valuable to the Skylab mission. Future manned missions should provide as large and as many windows as is practical; these should be located to allow coverage of the exterior of the vehicle. The larger size would allow better positioning and easier operation of photographic and TV cameras. External structures should be designed such that the window viewing angles are obstructed as little as possible.

Windows should also be provided in all internal hatches to provide visual perception between compartments. The size, location, and shape of such windows will depend upon their application.

2.12.4 Extra Vehicular Activity (EVA)

The Airlock Module provided the airlock compartment required for Skylab egress and ingress, and the life support provisions required to enable pressure suited crewmen to perform EVA tasks. Design provisions included:

- Gemini flight proven EVA hatch and two large internal hatches with windows (see Figures 2.12-7 and 2.12-8).
- Internal and external network of handrails for mobility and translation to EVA workstations (see Figure 2.12-9).
- EVA lighting to illuminate the EVA trail and workstations.
- Equalization valves manually capable of operation by the pressure suited crewmen to depressurize or pressurize the Airlock compartment.
- Two LSU Stowage Spheres mounted external to the Airlock compartment with the sphere opening flush to the tunnel wall for LSU management (see Figure 2.12-10).

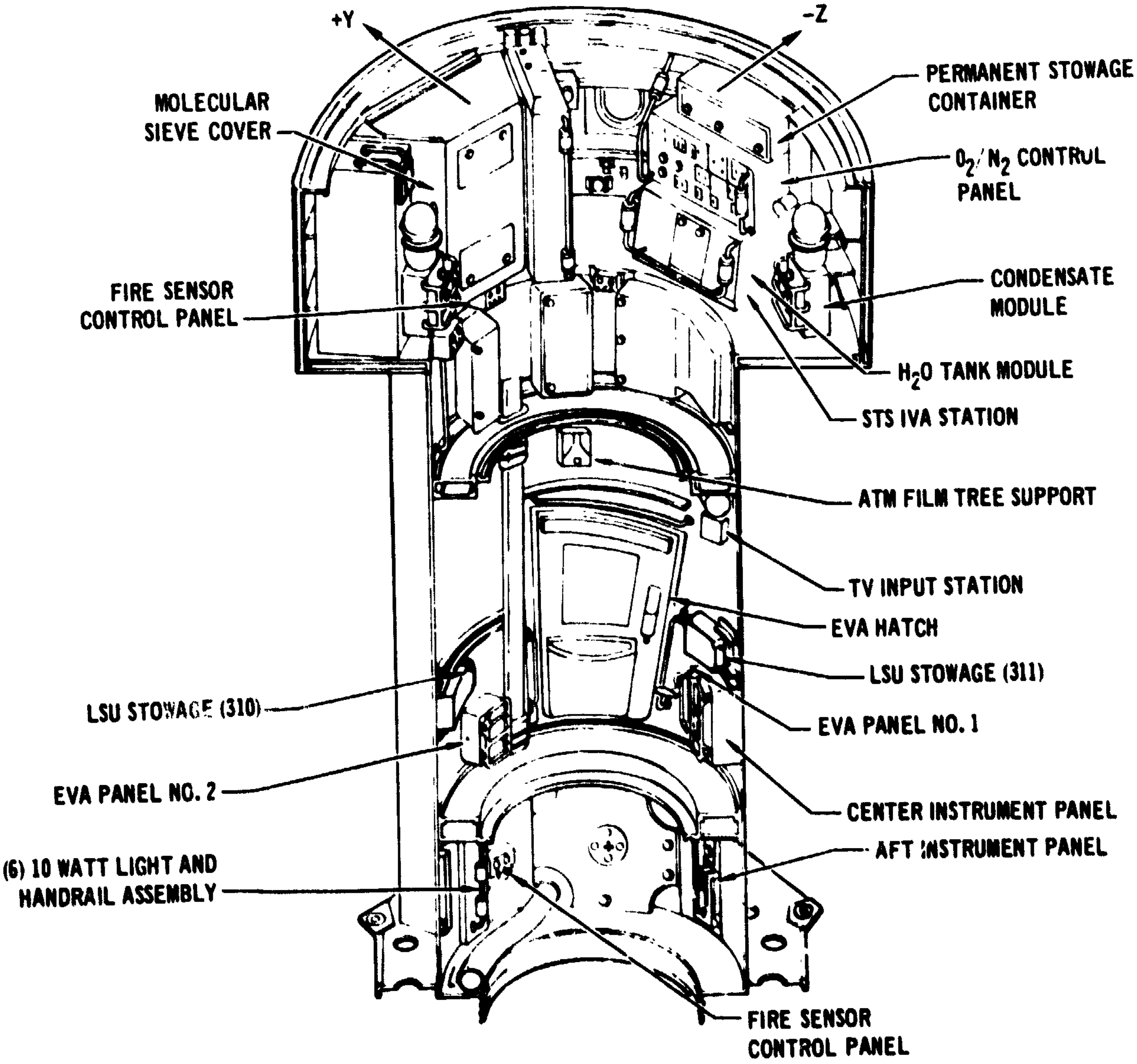


FIGURE 2.12-7 EVA COMPONENT (+ Y, -Z)

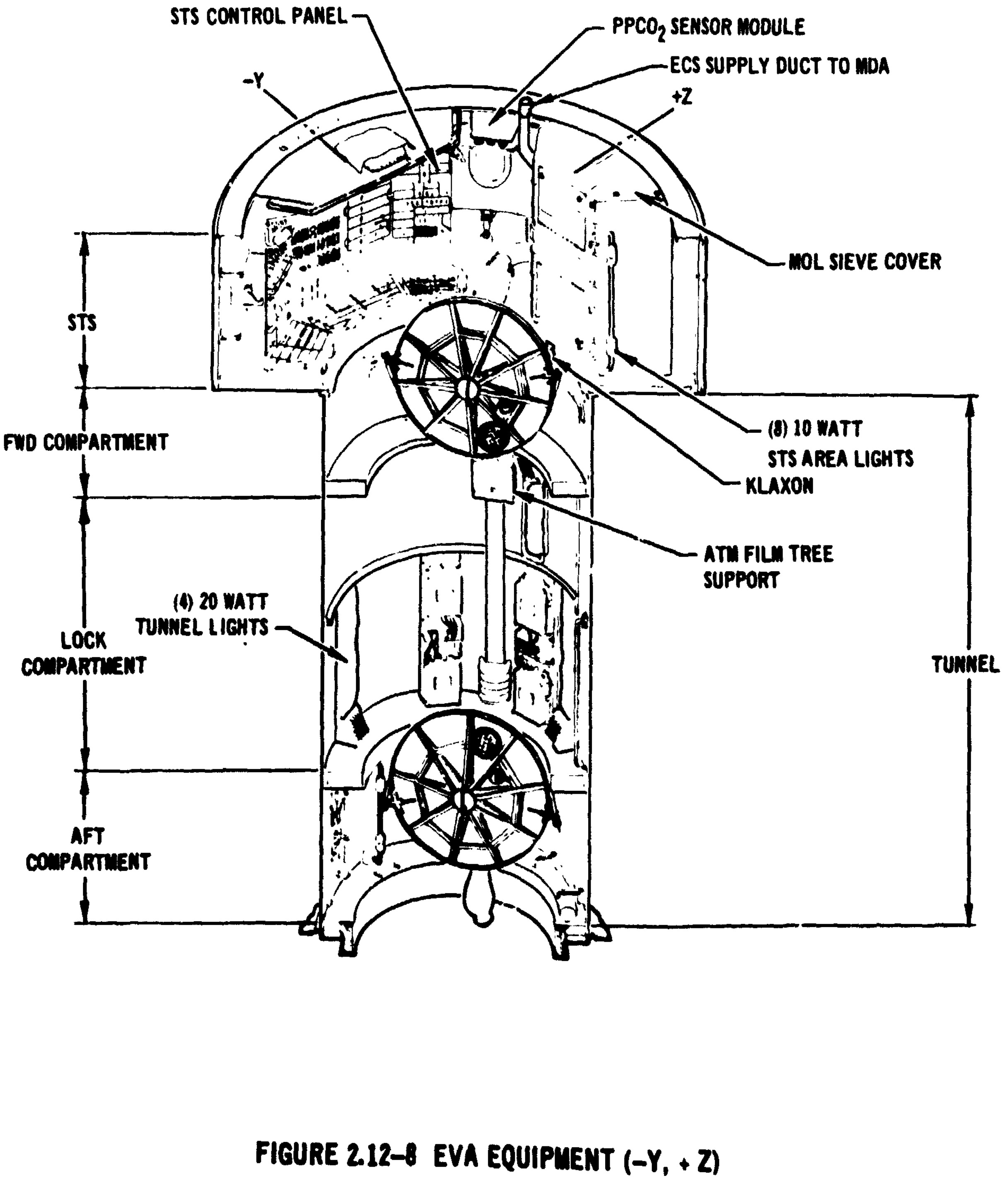
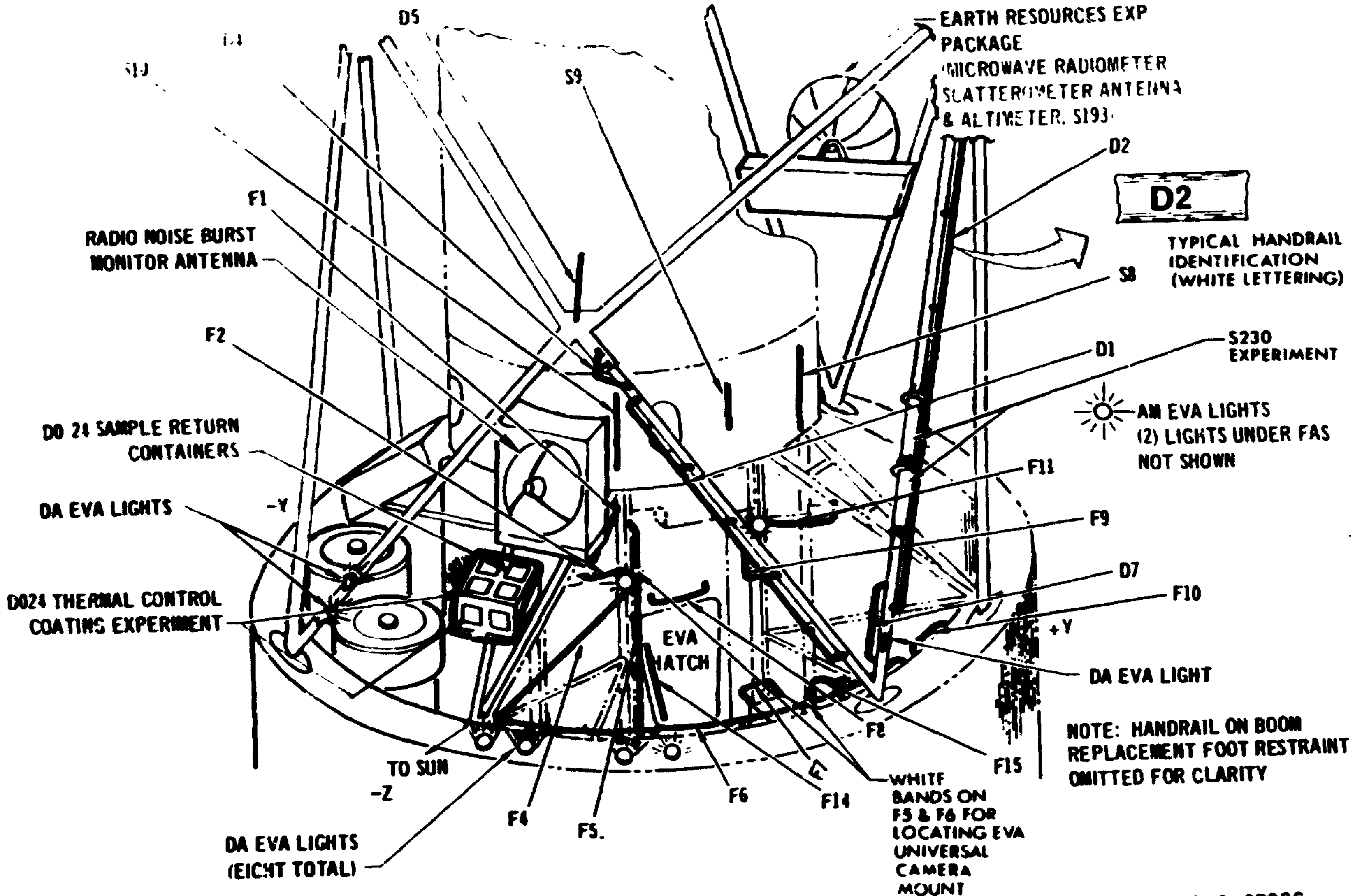
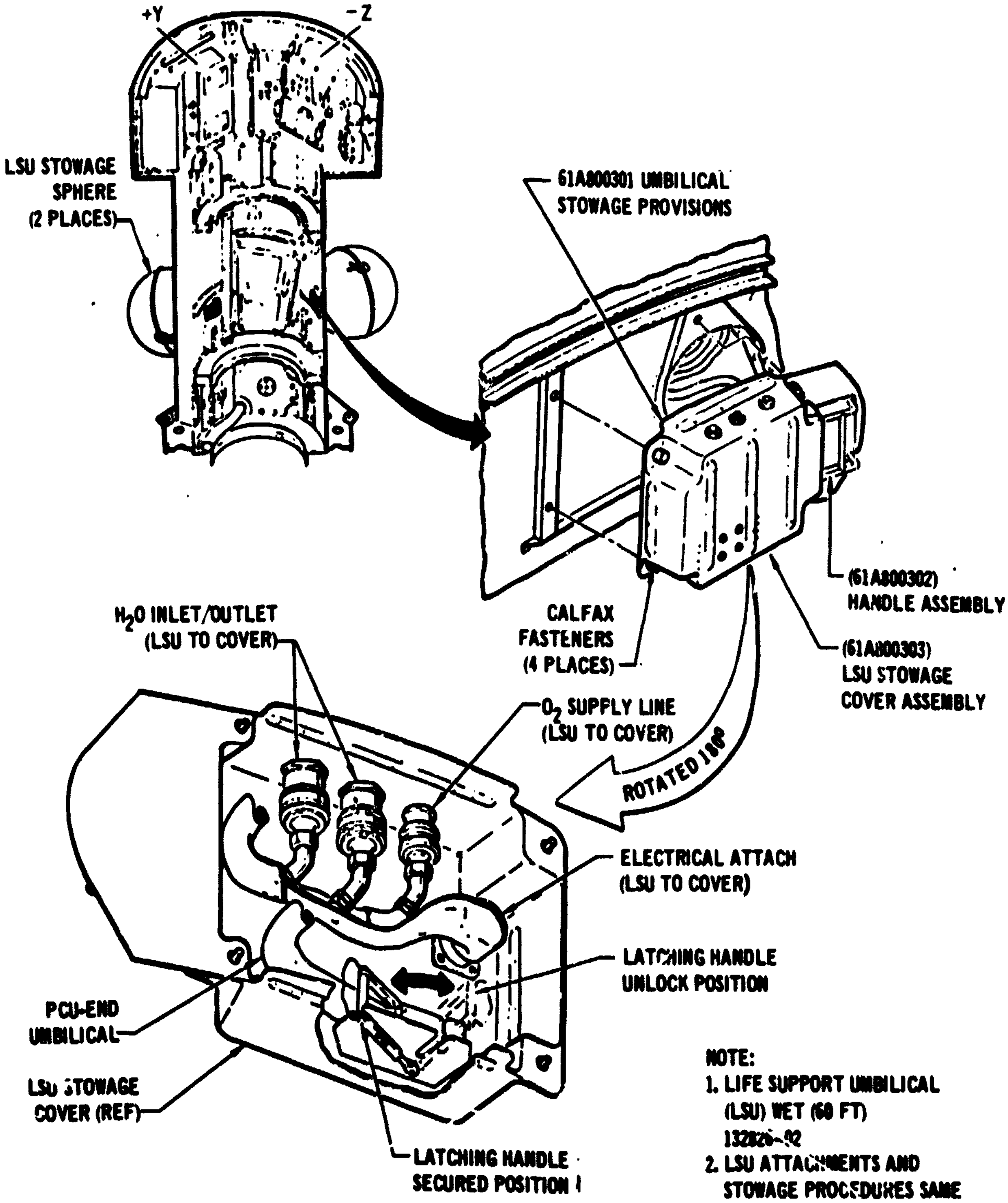


FIGURE 2.12-8 EVA EQUIPMENT (-Y, + Z)



HANDRAILS WERE MADE FROM ALUMINUM ALLOY (6061-T6) TUBE 1.25 INCHES IN DIAMETER FLATTENED TO A CROSS SECTION OF .62 INCHES X 1.41 INCHES WITH .31 RADIUS AT EACH EDGE. HANDRAILS WERE WELDED TO BASE PLATES FOR ATTACHMENT TO STRUCTURE. ALL EDGES WERE BROKEN AND ROUNDED TO .25 RADIUS MIN. FINAL FINISH WAS BLUE ANODIZE.

FIGURE 2.12-9 EVA HANDRAILS AND LIGHTING



NOTE:
1. LIFE SUPPORT UMBILICAL (LSU) WET (60 FT) 132826-02
2. LSU ATTACHMENTS AND STOWAGE PROCEDURES SAME IN TWO (2) PLACES

FIGURE 2.12-10 LSU STOWAGE

- Two LSU containers lids to restrain both ends of the LSU's and provide a smooth cover over the LSU stowage sphere openings (see Figure 2.12-10).
- Installation of the (GFE) VC and VS film tree receptacles in the Lock Compartment to assist in ATM Film handling.
- EVA control and instrument panels mounted in the Airlock Compartment. The two EVA panels each provided redundant LSU electrical, O_2 and H_2O connectors. The instrument panel provided displays of lock, aft, and OWS compartment pressures, LSU O_2 supply pressure, EVA lighting and Voice Record Controls (see Figure 2.12-11).
- IVA control panel and 3rd LSU O_2 and electrical connects were provided to support three suited crewman in the STS/MDA as a backup in case the Airlock couldn't be repressurized.
- Installation of the (GFE) foot restraints in the FAS located so the crewman would have two-handed access to the ATM Film Transfer Equipment (see Figure 2.12-12).
- Replacement work station adjacent to the EVA hatch to restrain the crewman for clothesline deployment, extendible boom replacement and manual boom operation task.
- Clothesline packets to contain the sun and center workstation clotheslines. Clothesline clips on the handrails were provided to hold the VC & VS clothesline out of the way of the EVA trail when not in use.
- Extendible boom control panel mounted adjacent to the EVA hatch for motorized operation of the VC & VS extendible booms from the FAS work-station.
- Velcro strips for attachment of EVA cue cards for the FAS workstation.
- Installation of (GFE) VC and VS film tree receptacles located in the FAS so that ATM film could be loaded on the extendible boom or clothesline by the EVA crewman in the FAS workstation.
- Two inflight replaceable, extendible booms to transfer the ATM film between the FAS workstation and the VC and VS workstations. A spare boom was located adjacent to the VC boom to serve as a replacement for either the VC or VS booms.
- D024 Experiment installation with handholds, experiment panel/return container attachment allowing one hand operation (see Figure 2.12-12).
- Installation of (GFE) LSU clamps located aft of the EVA hatch but within reach of the EVA crewman in the FAS workstation.

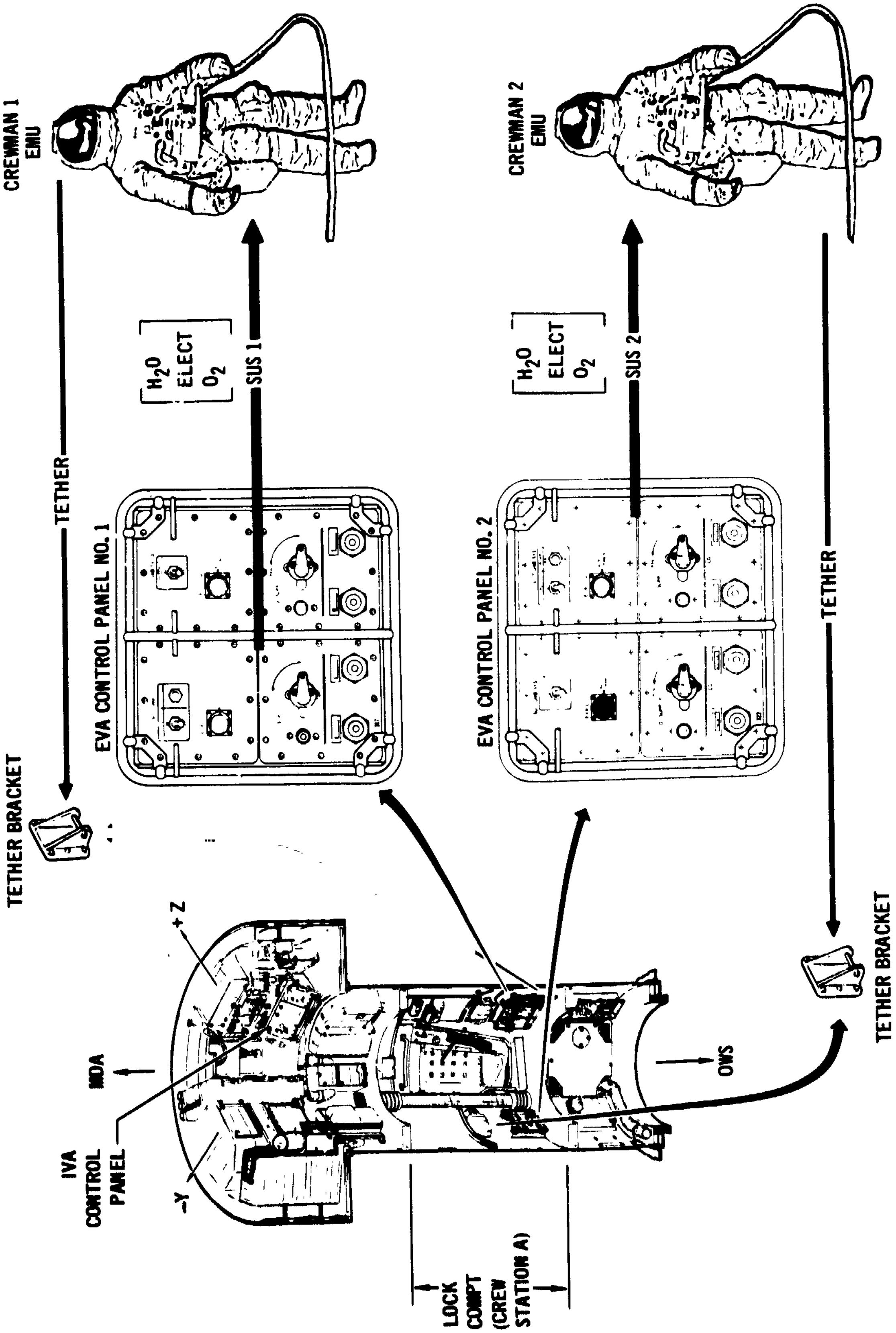


FIGURE 2.12-11 EVA PROVISIONS

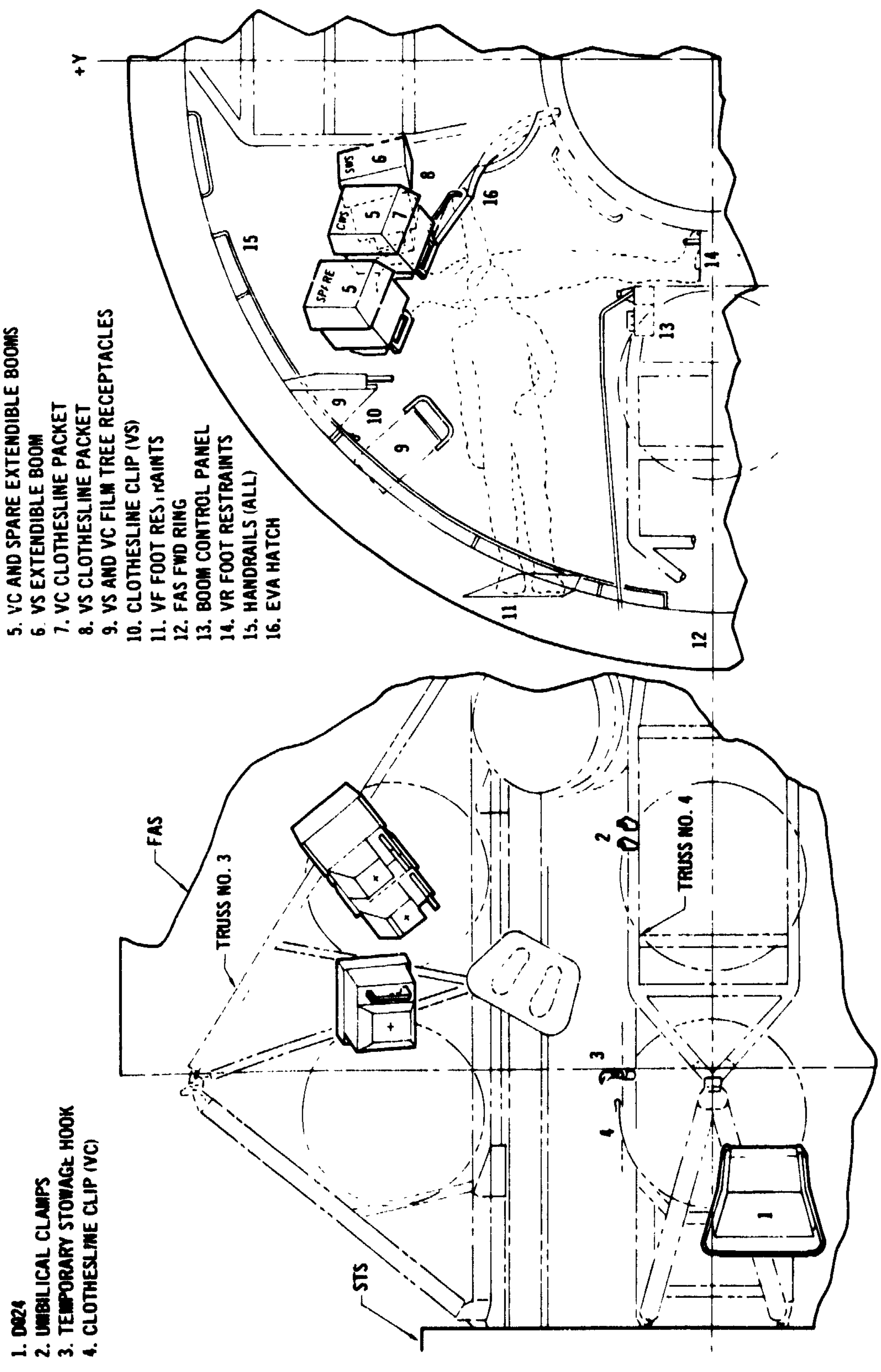


FIGURE 2.12-12 EVA WORK STATION

- Installation of a temporary storage hook located to provide a temporary, out-of-the-way restraint for EVA equipment, but within reach of the crewman at the FAS workstation.
- Launch stowage container for three GFE extendible boom hooks installed in the FAS so the boom hooks could be removed from the container and attached to the extendible booms from the FAS workstation.
- Sharp edge protection throughout the airlock and EVA areas. Close attention to eliminating sharp edges was also given to all external areas outside the normal EVA trail.

2.12.4.1 Mission Results

Nine successful EVA's were performed on SL-2, 3, and 4 verifying Airlock and EVA life support equipment design.

EVA flight results indicate the following:

- EVA hatch operation was good and hatch size was satisfactory for egress/ingress.
- Airlock compartment size was nearly optimum for two-man EVA with ATM film.
- Internal Airlock hatch sizes were good with no problems in handling hatches during opening and closing. Windows in the internal hatches were used during EVA to monitor and assist the two pressure suited crewmen in the lock compartment.
- Handrails were sufficient for crew translation to all EVA workstations. Additional handrails left on the STS from "wet" workshop were beneficial in performing the critical SAS Deployment EVA. Handrail color contrast was noted as being good.
- The depressurization rate of the Airlock was noted as being "just right."
- Managing and stowing two 60-foot umbilicals was easily performed for the planned tasks. Management during contingency tasks required considerable crew time and exertion.
- The ATM film tree receptacle locations were satisfactory to support the ATM film retrieval/replacement task.
- Water cooling for the LCG was sufficient to provide cooling for three suited crewmen, all on the same loop.

- The FAS workstation foot restraint location was satisfactory to handle the ATM film and operate the extendible booms.
- Extendible boom operation was excellent and on target at both sun and center workstations.
- D024 experiment was satisfactorily performed.
- EVA lighting was excellent.
- Boom hooks and stowage box accessibility was good.
- Special attention paid to sharp edge protection outside the normal EVA area around the DA made it possible to safely perform the important contingency EVA tasks, i.e., SAS deployment, rate gyro installation and ATM CBRM troubleshooting.

2.12.4.2 Conclusions and Recommendations

- Space maintenance and repair tasks can be accomplished by properly restrained EVA crewmen. Future spacecraft should have provisions for common attach receptacles incorporated around the spacecraft exterior so mating handholds and foot restraints can be attached to allow contingency EVA repair tasks.
- Future design of EVA equipment should consider in-flight maintenance or repair via EVA as a feasible operational mode.
- The airlock compartment for EVA should be a separate part of the vehicle so when in use it does not separate or isolate one part of the vehicle from another part.

2.12.5 Lighting

The AM lighting system provided the Skylab crews with exterior and interior illumination. The exterior lighting was used in performance of EVA activities. The interior illumination was used on the control panels and surrounding areas inside the AM, MDA and a portion of the OWS. The following subsystems made up the lighting system: general interior illumination system, meter lighting system, status light system, EVA lighting system and various controls and power for other modules' lighting systems.

Initial power and cost considerations for the Airlock program dictated the use of Gemini lighting hardware with illumination levels that bordered on minimum suitability. The Gemini EVA adapter work area/auxiliary target docking adapter lights were chosen for all initial Airlock lighting, both internal and external. A white AM interior was selected to achieve minimum contrast and maximize reflected light. The workshop volume utilized 20 of these lights attached to inflight installed cables for illumination. Two portable floodlights utilizing 1385 type bulbs supplemented the fixed lighting for both internal and EVA tasks.

Internal AM lighting design was modified after the Jan. 1967 crew review to eliminate crewman impact/bumping and high touch temperatures. This redesign mounted the Type 308 bulbs in a corner located reflectorized fixture.

Initial AM lighting underwent gradual modification as systems and structure changed to the final Skylab configuration. Figure 2.12-13 lists the AM applicable final Skylab lighting provisions and illumination levels.

On-board lights were crew controlled. The lighting system controls were located on: the STS Control Panel 207; on the EVA Support Control Panel 316; and on OWS, LTG, TCS Control Panel 390. The circuit protection devices for the lighting system were located on Circuit Breaker Panel 202.

FUNCTION	LIGHTING DESCRIPTION	ILLUMINATION LEVEL
EVA (FAS Area)	Four Gemini EVA lights on AM trusses adjacent to EVA hatch. Docking light (-Z axis) provides illumination for D024 experiment module.	Twenty-one candlepower Type 308 bulbs. Two to five foot candles (ft. cd.) in EVA FAS area.
EVA (Film Transfer Area)	Eight 25-watt floodlight units using 1385X bulbs to floodlight ATM EVA film transfer area. Four units mounted on FAS fwd ring and four mounted on DA.	Average of 25 ft. cd. at 3 ft. from single unit. Beam 30° wide. 45 ft. cd. value at 30° off axis. Estimated 25 ft. cd. 6 ft. forward of FAS.
EVA (ATM Work Station Areas)	Twelve Gemini EVA lights on ATM to illuminate work stations and camera areas. Five lights on center work station and seven on sun end work station.	Twenty-one candlepower Type 308 bulbs. Estimated from 5 to 10 ft. cd. on work areas.
STS (Internal)	Fourteen 10-watt (6 cp) Type 304 bulbs mounted in cylindrical handrail light assys. Light transmitted thru frosted Lexan sleeve, tempered glass and teflon tape wrapping layers. Light groups dimmable by variable pulse width control unit. Fwd. tunnel illuminated with STS lights. Bulbs easily replaceable inflight.	1.8 to 2 ft. cd. average illumination in STS with MDA lights operating. Values taken at 28 volts bus voltage.
Lock Compartment	Four corner mounted reflectorized units utilizing 308 Type incandescent bulbs. Domed glass lenses over units with wire grid provided temperature and impact protection. White paint on all walls. Selection of 0, 2, or 4 lights available.	Twenty-one candlepower bulbs. Average light levels from six to nine ft. cd. Even illumination with minimum shadowing.
Aft Compartment	Six 10-watt (6 cp) type 304 bulbs in handrail units. (Same as STS) selection of 0, 2, or 4 lights available on C&D panel.	Estimated at 4 ft. cd. average value.
Indicators	Display panel meters provided with integral lighting fully dimmable by variable pulse width control.	Two sub-miniature .15 candlepower lamps per indicator.

FIGURE 2.12-13 LIGHTNING PROVISIONS AND ILLUMINATION LEVELS

2.12.5.1 General Interior Illumination System

The general interior illumination system provided STS panel illumination and area illumination in the STS, lock and aft compartments. These lights and the other module lights were crew controlled. The system was successfully tested at MDAC-E and at KSC. A waiver was requested and granted on the minimum luminosity requirements of STS compartment lights. During the mission the general interior illumination system functioned as expected.

A. Design Requirements

(1) STS Lights - Originally four shock mounted 20-watt light assemblies illuminated the STS compartment. These lights were replaced with eight 10-watt handrail mounted lights, which reduced the localized hot spots and deleted the shock mount requirements. Toggle switch control of these lights was replaced with variable dimming controls. STS panel illumination system was added; it consisted of a variable dimming control and six 10-watt handrail lights surrounding the instrument and circuit breaker panels.

(2) Lock Compartment Lights - Four 20-watt lights with shock mounts and toggle switch control were added to illuminate the lock compartment.

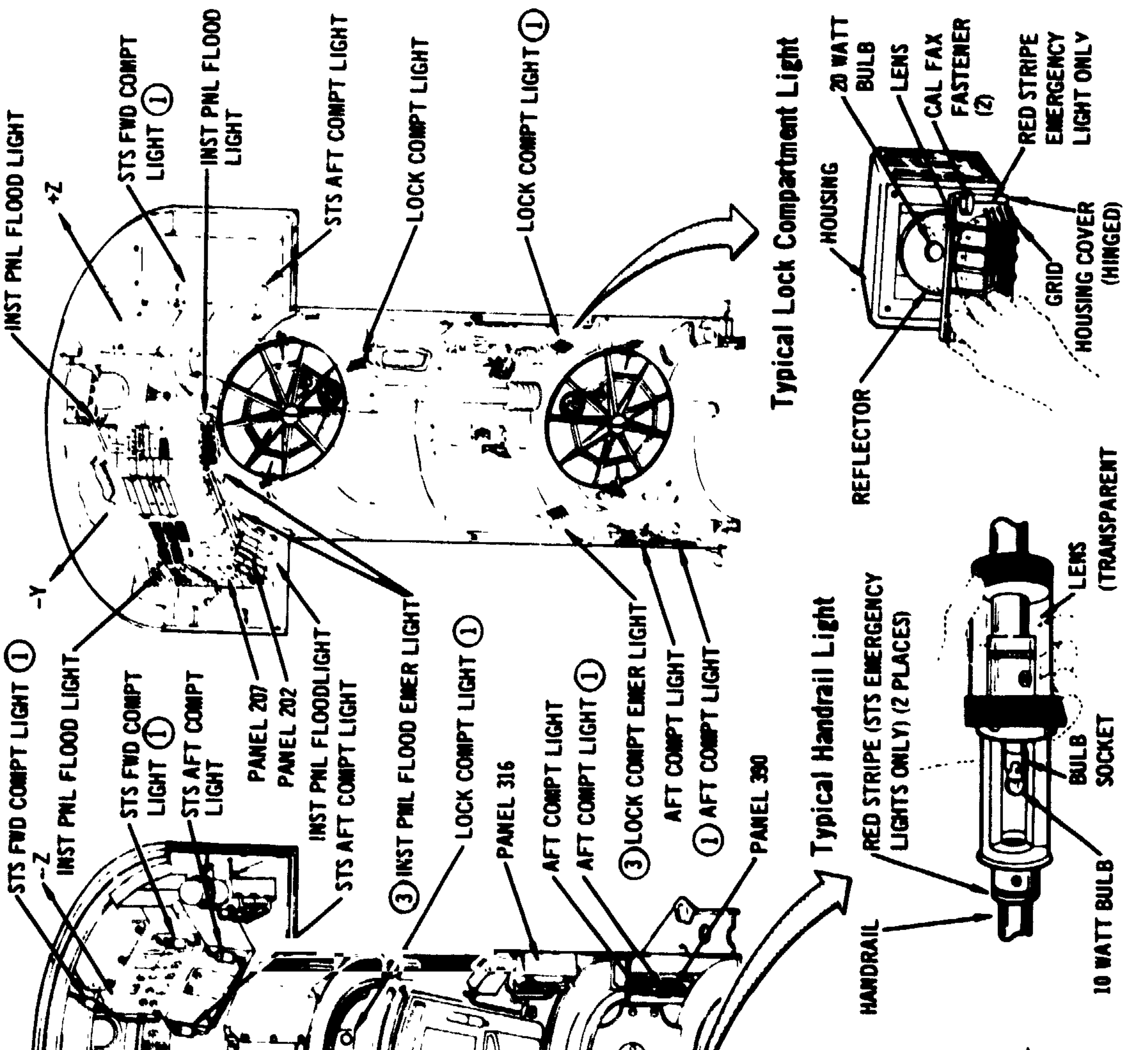
(3) Aft Compartment Lights - Originally three shock mounted 20-watt lights illuminated the aft compartment. These lights were replaced by six 10-watt handrail mounted lights with toggle switch control.

(4) MDA Compartment Lights - AM power and toggle switch control was provided for crew control of the MDA forward and aft compartment lights via MDA relay circuits.

(5) OWS Initial Entry Lights - AM power and toggle switch control was provided for crew control of the OWS initial entry lights.

(6) Emergency Lighting - AM, MDA and OWS emergency lighting was provided if the lighting system power sources failed. The emergency lights consisted of two MDA compartment, two STS instrument panel, one lock compartment and eight OWS initial entry lights.

B. System Description - The AM general illumination system light locations are shown in Figure 2.12-14. The 10-watt handrail light bulbs were replaceable by sliding the cylindrical shaped lens along the handrail



NOTES:

① LIGHTS POWERED BY AM BUS 1

2 UNLESS NOTED OTHERWISE LIGHTS WERE POWERED BY AM BUS 2.

③ LIGHT ALSO USED AS AN EMERGENCY LIGHT

FIGURE 2.12-14 GENERAL ILLUMINATION

exposing the bulb. The 20-watt light bulbs were replaceable by loosening the Calfax fasteners allowing the hinged housing cover to rotate exposing the bulb.

(1) STS Illumination - The four STS aft compartment lights, the four STS forward compartment lights and the six STS instrument panel lights had individual controls located on the STS Panel. The light dimmer control and electronics assemblies, utilizing AM bus power, powered the lights directly for bright or indirectly by variable pulse width power for dimming.

(2) Lock Compartment Lights - The four lock compartment lights were powered in pairs from each AM bus. A toggle switch control, selected all four lights for bright and two lights for dim.

(3) Aft Compartment Lights - The six handrail mounted aft compartment lights were powered in groups of three from each AM bus. A toggle switch on Control Panel 390, selected all six lights for bright and three lights for dim.

(4) MDA Compartment Lights - The MDA compartment light AM controls were located on the STS Control Panel 207. The MDA FORWARD 1-3 and MDA AFT 1-3 switches utilized AM Bus 1 power to control a MDA latching relay that powered MDA forward lights No. 1 and No. 3 and another MDA latching relay that powered MDA aft lights No. 1 and No. 3. In a similar fashion the corresponding MDA forward and aft lights No. 2 and No. 4 were powered by AM Bus 2 and controlled by a similar set of switches and relays. A MDA switch located near the axial docking port also controlled simultaneously all the MDA lights by utilizing the MDA latching relays and power from the AM buses.

(5) OWS Initial Entry Lights - The eight OWS initial entry lights, Figure 2.12-15, were initially powered in groups of four from each EPS bus and controlled by the OWS ENTRY light switch located on Control Panel 390. After crew entry into the OWS, power and control were switched to the OWS buses and controls.

(6) Emergency Lighting - Two voltage sensors were used to monitor the OWS and AM buses. If both OWS buses dropped below a prescribed voltage, the sensor energized AM relay circuits utilizing EPS control bus power to illuminate the eight OWS initial entry/emergency lights, Figure 2.12-15. If low AM bus voltages occurred, the other sensor would utilize AM relay circuits and EPS control bus power to illuminate one lock compartment, two STS instrument panel and two MDA compartment emergency lights, Figure 2.12-16.

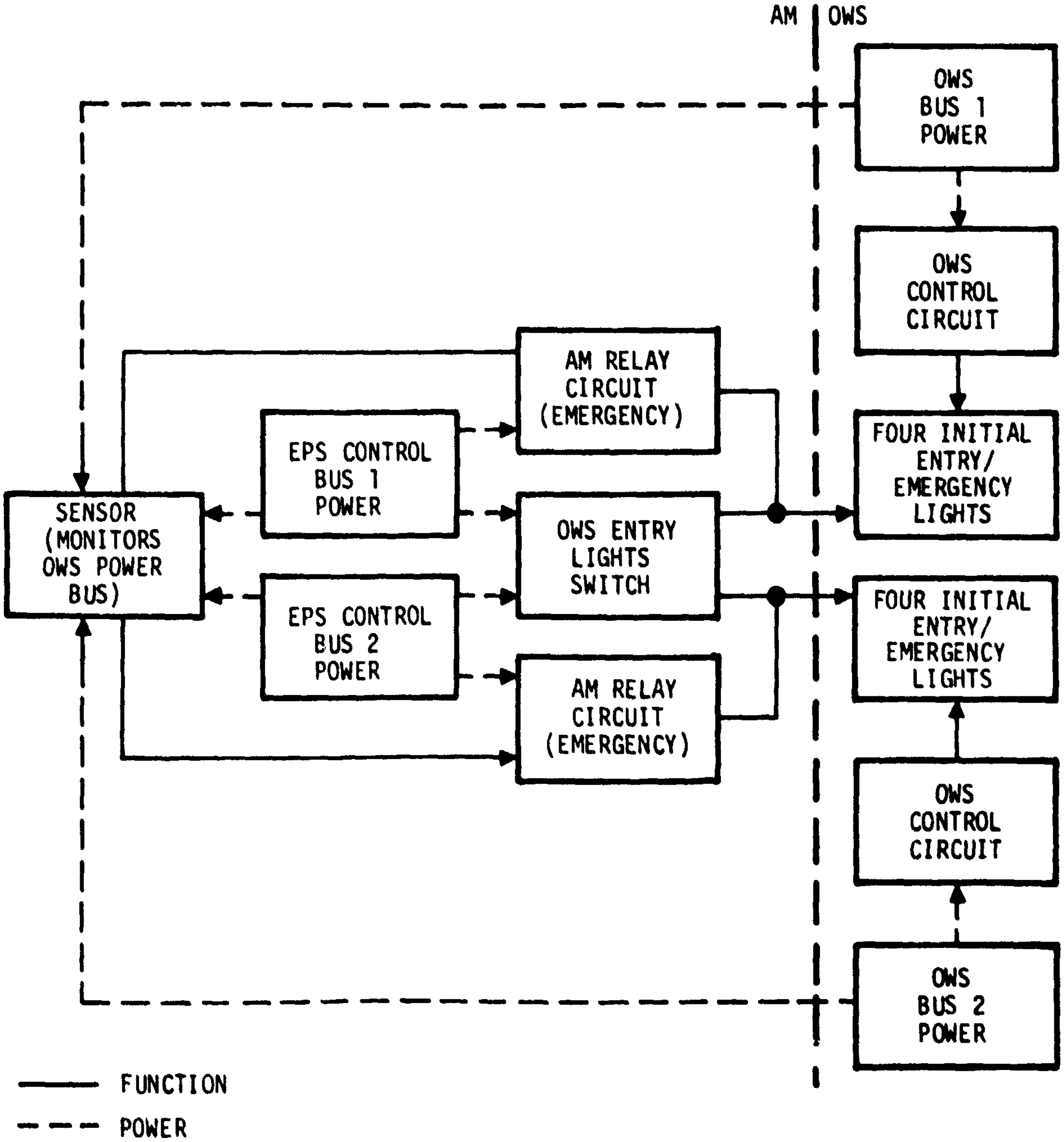


FIGURE 2.12-15 AM/OWS INITIAL ENTRY/EMERGENCY LIGHTS

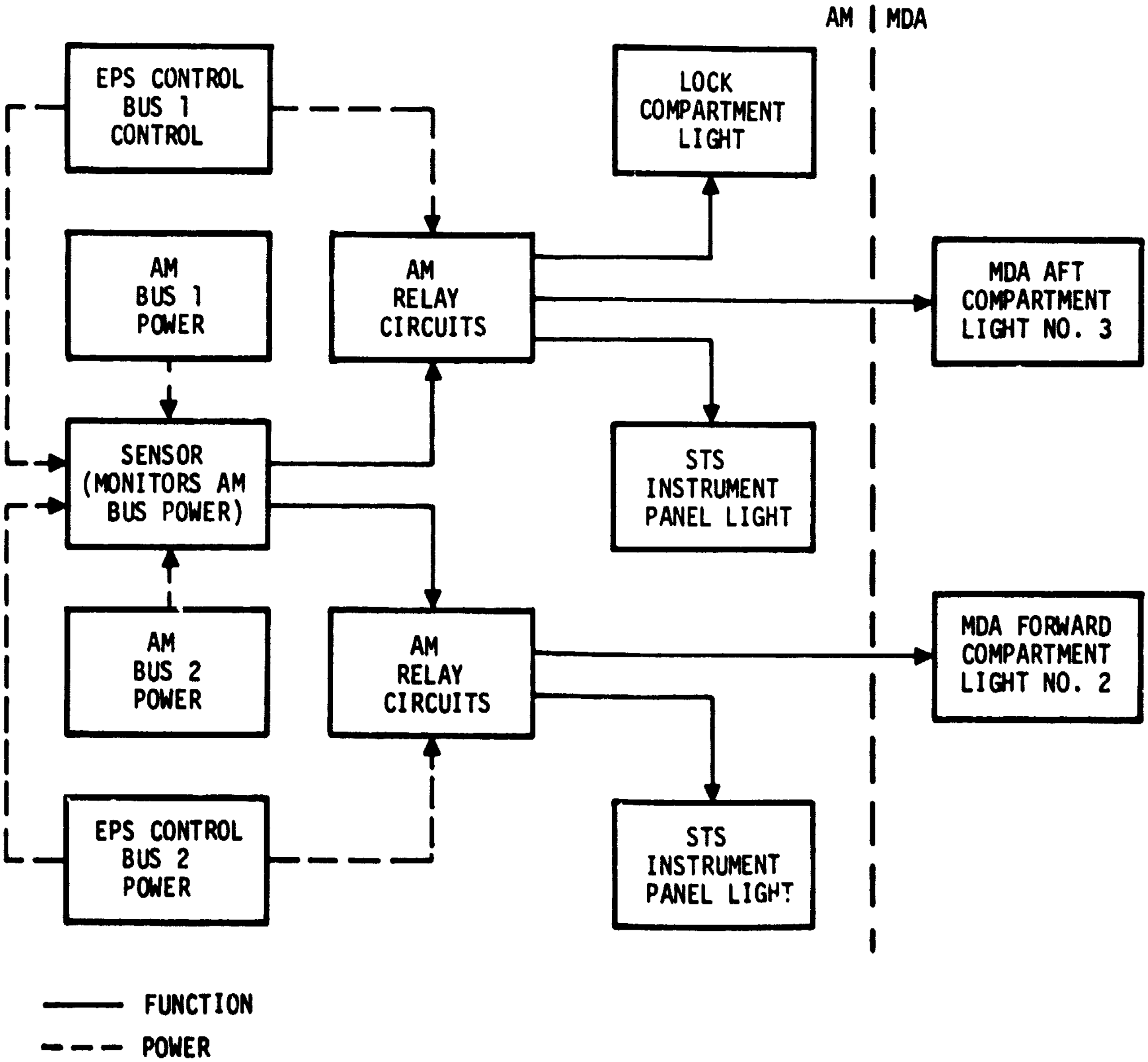


FIGURE 2.12-16 AM/MDA EMERGENCY LIGHTS

C. Testing - The lighting system was successfully tested at MDAC-E utilizing the test flow shown in Figure 2.12-17. The individual elements of the system are discussed below.

(1) MDAC-E - The general illumination system, was successfully tested. All prime and redundant circuits were verified for illumination and end-to-end operation to the respective interface simulators. During MDAC-E testing, the only significant lighting system problem was in the intensity of the lights in the STS and MDA areas. The flight crew evaluated the condition and deemed it acceptable for flight. A waiver was written to relieve the specification requirement.

(2) KSC - The general illumination system was verified for prime and redundant circuits and end-to-end operation including the AM, MDA and OWS.

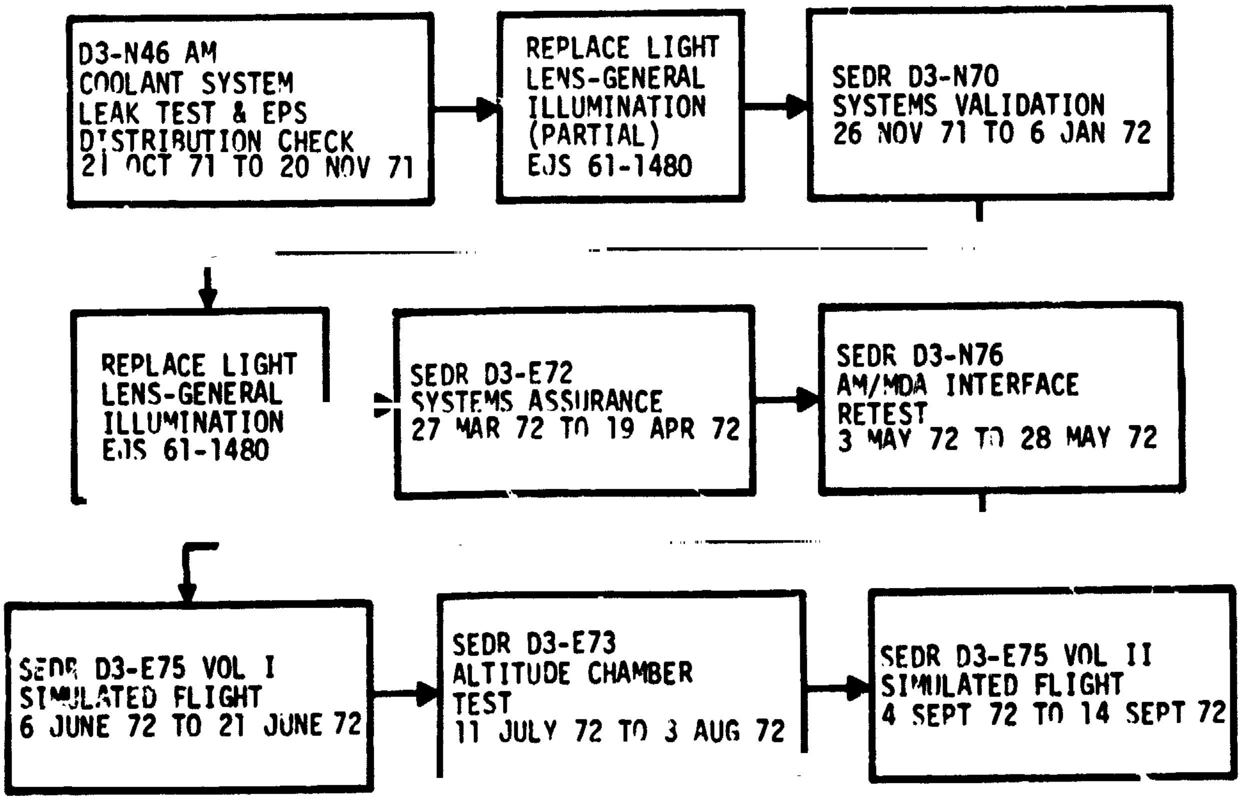


FIGURE 2.12-17 LIGHTING SYSTEM TEST HISTORY – MDAC–E

D. Mission Results

(1) SL-2 - One STS instrument panel handrail light ceased to illuminate. No attempt was made by the crew to replace the bulb. The crew utilized only the maximum illumination level on the variable dimming controls in the STS compartment. They also indicated that the AM lighting was the "nicest" in the whole cluster.

(2) SL-3 - The one STS handrail light bulb that ceased to illuminate on SL-2 and approximately 12 handrail light bulbs that ceased to illuminate on SL-3 were successfully replaced. Two MDA aft lights No. 2 and No. 4 were replaced but failed to respond to the MDA AFT 2-4 light switch control on the Control Panel 207. While trouble-shooting, the crew cycled the switch and discovered that when the switch was held in the "momentary on" position, the lights would illuminate. It became apparent that either the MDA latching relay would not remain latched or that the amount of contamination on the relay contact was sufficient to prevent conduction unless an additional force was applied to the contact by continuously applying power to the latch relay coil. After further troubleshooting the MDA relay latched in and powered the lights continuously. The crew taped the MDA AFT 2-4 switch as a reminder to control those lights by the switches that were an integral part of the light assemblies. A new deactivation procedure for SL-3 and a new activation/deactivation procedure for SL-4 was developed so the MDA relay would not be reset.

(3) SL-4 - Light bulbs were successfully replaced as necessary, crew did not keep track of the number of bulbs replaced. No anomalies in the lighting system were reported.

2.12.5.2 Meter Lighting System

The purpose of the meter lighting system was to enhance the legibility of the STS instrument panel and lock compartment panel meters. The system was successfully tested at MDAC-E and at KSC. During the mission the meter lighting system was crew controlled and functioned as planned.

A. Design Requirements - The STS instrument panel meters were originally controlled by a toggle switch, and light dimming was accomplished by switching a resistor in series with the light. Eventually, this toggle switch and resistor combination was replaced by a variable dimming control.

B. System Description - The thirty-two meter assemblies located on the various STS instrument panels were individually provided with internal illumination. The intensity of the meter lights was controlled by a variable dimming control, which operated the same as the STS dimmer ci[illegible]. Each meter had two non-replaceable light bulbs connected in parallel for redundancy. The lighting for the two lock compartment panel meters was controlled by a toggle switch. If all or part of the meter lighting system had ceased to function, the STS instrument panel or lock compartment general illumination lighting would have been used to illuminate the meters.

C. Testing

(1) MDAC-E and KSC - The meter lighting system was successfully tested, and all portions of the circuit were verified for end-to-end operation. Only one problem resulting in corrective action was discovered in testing. "Dim" meter lights on Panel 206, was resolved by meter replacement at the launch site.

D. Mission Results

(1) SL-2 - The crew indicated that the meter lighting system was seldom used and that the STS instrument panel lights and general illumination lights were normally used to view the meters. No anomalies in the meter lighting system were reported.

(2) SL-3 & SL-4 - No anomalies in the meter lighting system were reported.

2.12.5.3 Status Lights System

The status lights were provided to indicate operational status of the ECS, I&C, and condensate control systems. EPS status lights are covered in Section 2.7. System performance sensors contained within the individual systems controlled the illumination of the status lights. The lights were successfully tested at MDAC-E and at KSC. During the mission the status lights operated as planned.

A. Design Requirements - Originally two annunciator panels with provisions for 14 lights indicated system performance status. These panels were later replaced with individual status lights placed near the associated controls which provided a better control/light relative location. A circuit for verifying the integrity of the status light bulb filaments was required.

B. System Description - The status light functions and sensors are shown in Figure 2.12-18. When one of the monitored systems changed status, a sensor would actuate utilizing AM bus 2 power to illuminate the appropriate status light. In each case an alternate on-board and/or telemetry indication was available to monitor system performance.

SYSTEM	SENSOR	STATUS LIGHT FUNCTION
ECS	LEVEL INDICATOR SWITCHES	PRI & SEC COOLANT LOOP "RES LO"
ECS	PRESSURE SWITCHES	ATM COOLANT PUMPS "LO ΔP"
I&C	INSTRUMENTATION PACKAGE 2B	TAPE RECORDERS "STOP" 1, 2, & 3
I&C	CONTROL RELAYS	TAPE RECORDING "DATA", "EXP 1", & "EXP 2"
CONDENSATE CONTROL	PANEL SWITCH	CONDENSATE VENT HEATER "PRI" & "SEC"

FIGURE 2.12-18 STATUS LIGHT SENSOR VERSUS FUNCTION

C. Testing - MDAC-E - During preflight testing, a considerable amount of illumination time was expended on the EPS status lights, and a number of these lights failed when the life expectancy was exceeded. As a result, all EPS status light assemblies on STS control panels 205 and 206 were replaced prior to flight. The ECS, I&C and condensate control system status lights and the antenna lights illumination times plus the expected illumination time in flight plus a safety margin resulted in a total illumination time of less than the minimum life expectancy of the lights. For this reason, these lights were not changed out.

D. Mission Results - SL-2, SL-3, and SL-4 - The system provided adequate indication of system status. There were no unscheduled status illuminations with the exception of the "PRI COOLANT RES LO" status light which illuminated during SL-3 mission alerting the crew and the ground of the loss of the primary system coolant fluid.

2.12.5.4 EVA Lighting System

EVA lighting provided illumination of the area around the FAS work station and the EVA trail to the ATM. Hatch lights illuminated the AM egress/ingress area and the FAS work station. The white docking light was also utilized to provide additional illumination around the D024 experiment area. EVA lights were controlled from the AM. The AM portion of the EVA lighting system was successfully tested at MDAC-E and an overall electrical test including the AM and ATM was successfully accomplished at KSC. During flight, the EVA lighting system functioned as planned.

A. Design Requirements - Originally six EVA lights were provided on the SLA. During the conversion to the dry workshop, the six SLA EVA lights were replaced with six EVA lights mounted on the FAS and DA to illuminate the EVA trail. ATM EVA light control was added to the AM. The EVA hatch light control circuit was expanded to include the AM white docking light. This allowed the AM white docking light to be controlled from either the docking light or hatch light control circuits. Two lights were added to provide additional illumination for D021 experiment area. After D021 experiment was deleted, the two D021 lights were retained as DA EVA lights for ATM EVA trail illumination.

B. System Description - The EVA light controls were located on the EVA Support Panel 316. The AM EVA light switch utilized AM Bus 1 power to illuminate two hatch and one white docking light. The switch also utilized AM Bus 2 power to illuminate the other two hatch lights, Figure 2.12-19. The DA EVA light switch controlled the eight EVA lights mounted on the FAS and DA. Each of the AM buses powered four lights. The ATM EVA lights switch controlled relays in the ATM which utilized ATM power to illuminate the ATM EVA lights. AM EVA light levels exceeded JSC specification levels by an estimated factor of 15 and incorporated sufficient redundancy so planned night EVA's could be conducted with approximately 80% of the lights inoperative.

C. Testing - The EVA lighting system was successfully tested at MDAC-E. All prime and redundant circuits were verified for illumination and end-to-end operation to the ATM interface simulator.

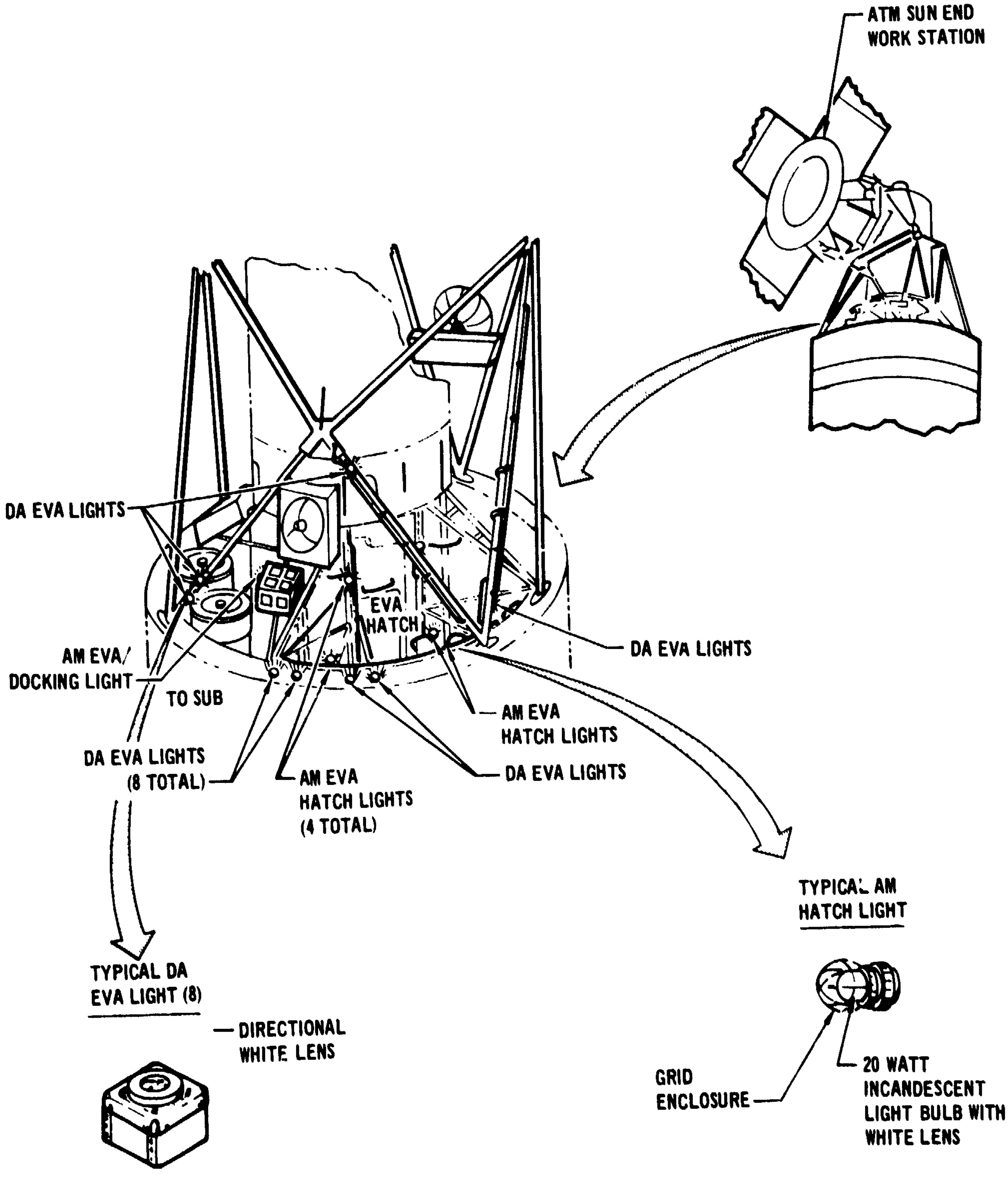


FIGURE 2.12-19 EVA LIGHTS

D. Mission Results

(1) SL-2 - The crew during debriefing indicated that the AM EVA lighting was excellent with no shadow problems, e.i., it was easy to see in shadows. The EVA lighting system functioned as planned with no hardware failures.

(2) SL-3 - The crew indicated the EVA lighting system was more than adequate and functioned as planned with no hardware failures.

(3) SL-4 - The system functioned as planned with no hardware failures.

2.12.5.5 Conclusions and Recommendations

The lighting system performed as expected. The basic design utilized flight qualified hardware and incorporated proven technology with a conservative design approach. The AM lighting system design objectives were met and no unexpected hardware failures occurred - some light bulb filament failures had been anticipated. The interior lights were made readily changeable in the event of a light bulb filament failure. The system proved more than adequate.

A. Conclusions - The final Airlock lighting configuration was considered excellent in the EVA and internal lock compartment areas. Lighting in the STS was marginal.

The initial design of the STS handrail lights resulted in average illumination levels of 5 ft. candles. Subsequent design changes resulted in final values of 1.8 to 2.0 ft. candles. These changes were as follows:

- PCSR request for removable mole sieve covers eliminated four STS lights (22% light reduction).
- Material flammability requirements changed single frosted Lexan lens to Lexan, glass and teflon tape layers with resultant light loss of estimated 50%.
- Structural cross section increased as result of cost saving change from machining to casting. Light reduction of estimated 10-15% of initial values resulted.
- MDA light output was reduced with resultant reduction of light across STS interface.

Emergency lighting utilized 2 STS and one lock compartment light which were activated upon failure of both AM buses. Light levels were considered very good and all AM internal functions could be operated satisfactorily using these lights.

B. Recommendations

(1) Minimum touch temperature should be raised from 105°F to 120°F for metal objects and 130°F for glass and lower conductivity materials. NASA Bioastronautics Data Book gives voluntary touch limits of 120°F for 3 seconds on metal objects. AM lights with low conductivity surfaces exceeded 130°F with no crew problems. Present 105°F temperature limit whould be specified only when crewman is in a fixed position near the lights for long periods.

(2) Lighting specifications should be contractually implemented as a "guide" status only. Specification of desirable or suitable lighting is difficult since it depends on the specific application and many factors such as intensity, contrast ratios, shadowing, color, etc. Lighting suitability should be determined by qualitative evaluation using simulators or mock-ups.

(3) Light bulbs replacable from the front of the panel should be incorporated in the design wherever practical.

2.12.6 Stowage

The philosophy at the onset of the Skylab Program was to stow everything for launch in the Airlock since the S-IVB stage would be used initially as part of the launch vehicle. Activation of the AM/OWS then included transfer of many of these items from the launch location (AM) to predetermined on orbit locations in the OWS.

The concept for restraining stowage items in the Airlock Module initially was to hardmount or restrain each item separately. At that time the Airlock provided stowage for such items as pressure suit assemblies, the scientific airlock, equipment, food lockers, personal hygiene, waste management equipment, cameras, life support umbilicals, hand held maneuvering unit, and lithium hydroxide canisters. There were also several lockers to be used for undefined stowage.

When the decision was made to dry launch the OWS, the launch stowage location of food, personal hygiene, waste management equipment, cameras, et al was changed from the Airlock to the OWS. Also, about this time, the ECS was revised to utilize molecular sieves which allowed the deletion of the lithium hydroxide canisters. Subsequently, launch stowage for the Airlock Module evolved to include items for in-flight maintenance of the Airlock/OWS, as defined in the stowage list I-SL-002.

2.12.6.1 Design Description

The final design of Airlock Module stowage provisions included items hardmounted separately or restrained either separately or collectively. Hardmounted items are held in place by Calfax fasteners while restrained items are held in place by mosite foam. Initially, stowage containers were lined with foamed-in-place NOPCO foam to restrain individual components as they were on Gemini and Mercury. NOPCO foam was disapproved for use due to its failure to meet flammability requirements of MSFC-SPEC-101A. After evaluating different types of foam, Mosite rubber, used in conjunction with mechanical clamping designs was selected as the replacement for NOPCO foam.

All stowage locations were identified by a number. The numbering system utilized, to help the crew locate a specific stowage locker, was to start in the MDA at the +Y axis with No. 100, proceed clockwise, looking down on the stack prior to launch, and aft through the AM to the aft end of the OWS. Each section of the vehicle had its own assigned set of numbers, e.g. the STS was allocated Nos. 200 through 299, the tunnel was allocated Nos. 300 through 399. In addition to numbering each stowage location, every locker had a decal which

tabulated the items in that locker. Following is a detail description of each stowage location.

A. Stowage Locker M168 - This stowage locker, shown in Figure 2.12-20, was approximately 12" x 24" x 48" and was transferred from the STS to the MDA during SL-2 activation. It contained 28 Solids Trap and one Mole Sieve Fan; two Water Separator Plate Service Adapters, two Water Separator Plate Service Hoses. A Condensate Module was attached to the outside of the locker during launch.

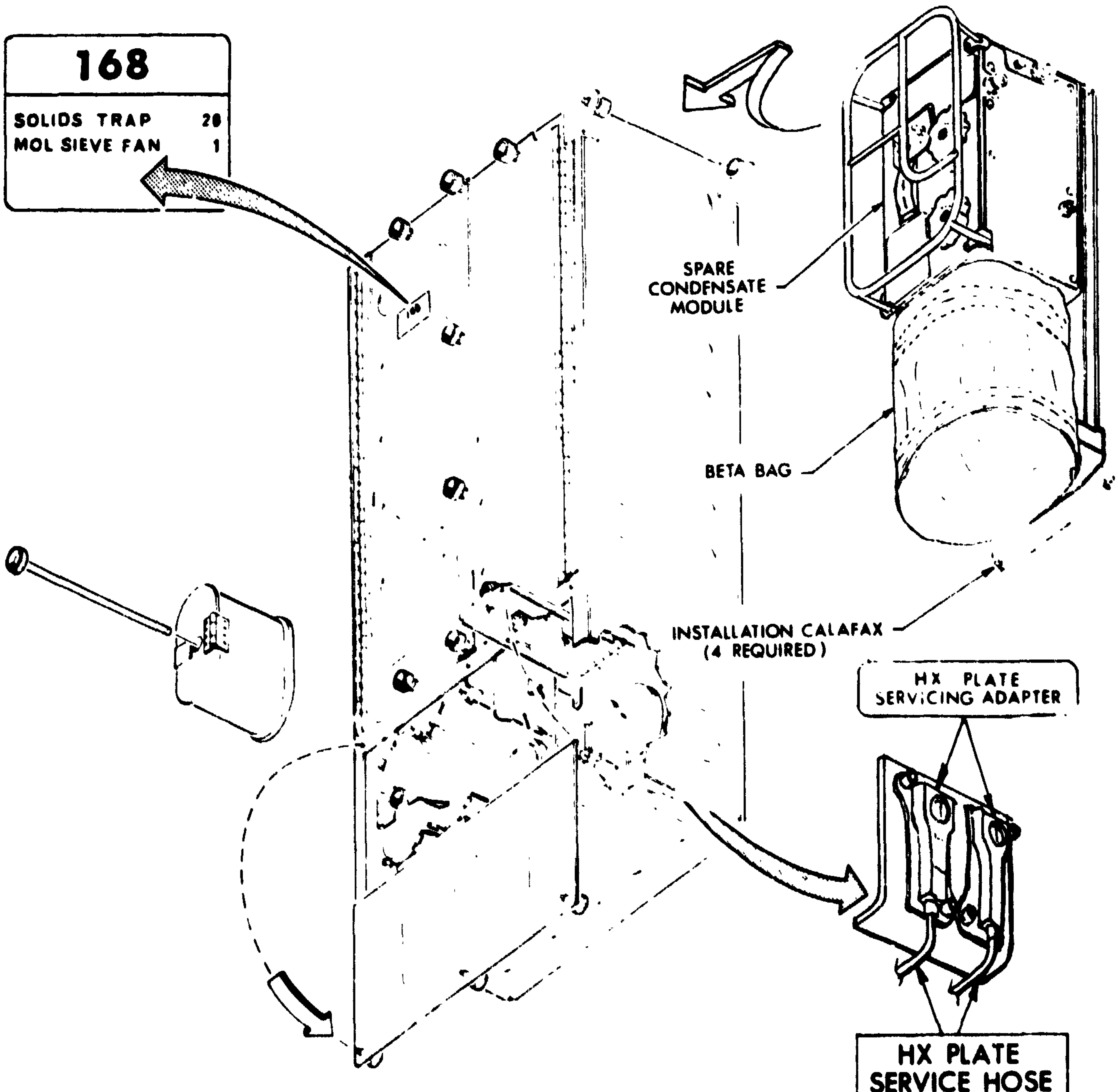


FIGURE 2.12-20 STOWAGE LOCKER M168

B. Stowage Location M200 - This location was assigned to a Speaker Intercom Assy (SIA) which was held in place by Calfax Fasteners. The SIA was transferred to the MDA during SL-2 activation.

C. Stowage Location M201 - This location, shown in Figure 2.12-21, was assigned to Teleprinter Paper Stowage. There were 26 air tight tubes - each contained six rolls of paper.

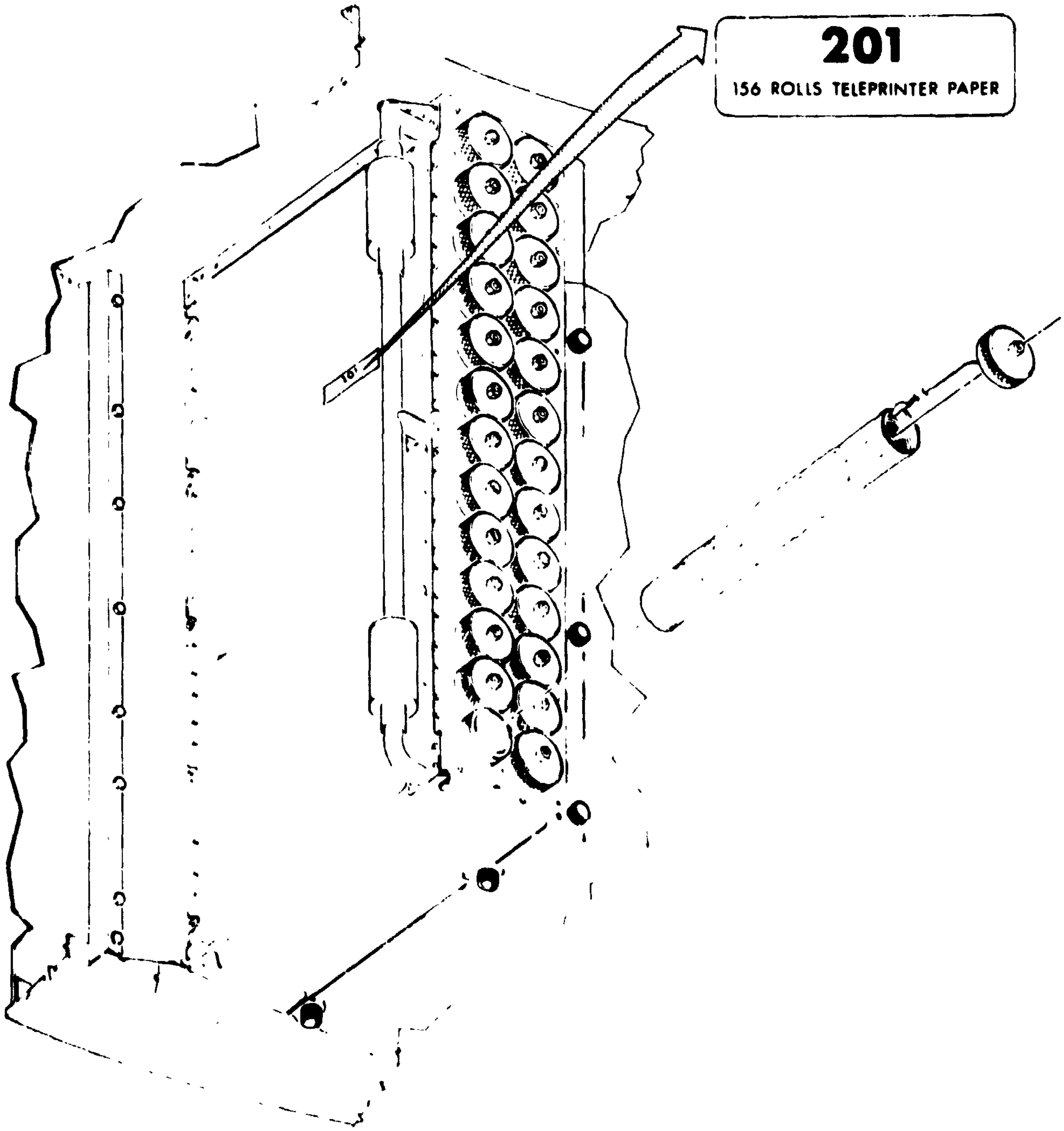


FIGURE 2.12-21 STOWAGE LOCATION M201

D. Stowage Locker 202 - This stowage locker was designed with a hinge to allow it to swing away from the STS inner wall to provide access for changeout of the ATM C&D Filter. The contents of Locker 202 (shown on Figure 2.12-22) included: one Teleprinter, one Teleprinter Cartridge, one Inlet and one Outlet CO_2 Detector Endplate, one Condensate Tank Manual Pump, four Water Separator Plates, four Portable Timers, four Portable Timer Batteries, and twelve Portable Timer Tone Generator Batteries.

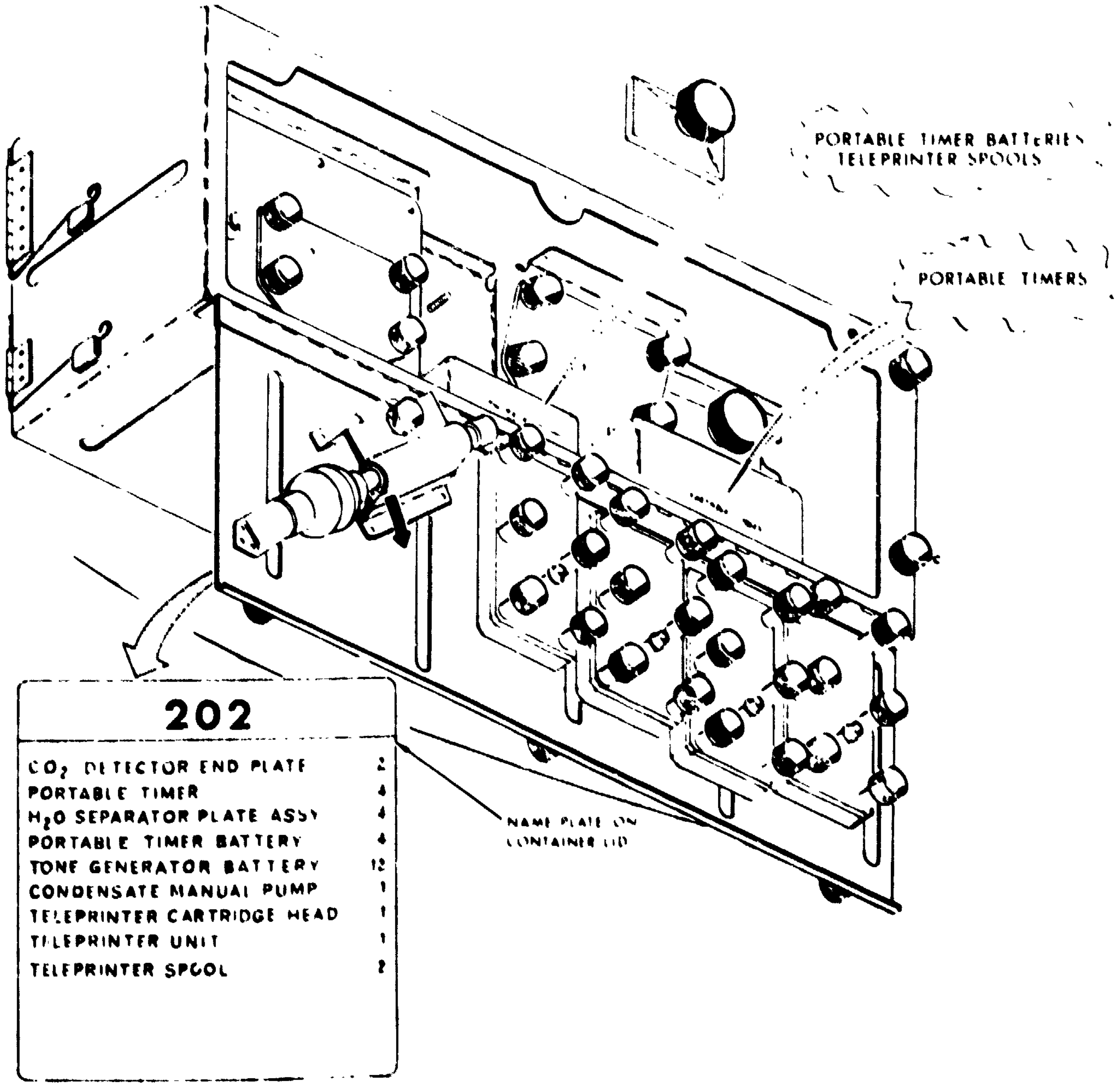


FIGURE 2.12-22 STOWAGE LOCKER M202

E. Stowage Location M208 - This location, shown in Figure 2.12-23, was assigned to a data file which had a hinged door for access. It was used during flight to retain checklists pertinent to the operation of the Airlock Module.

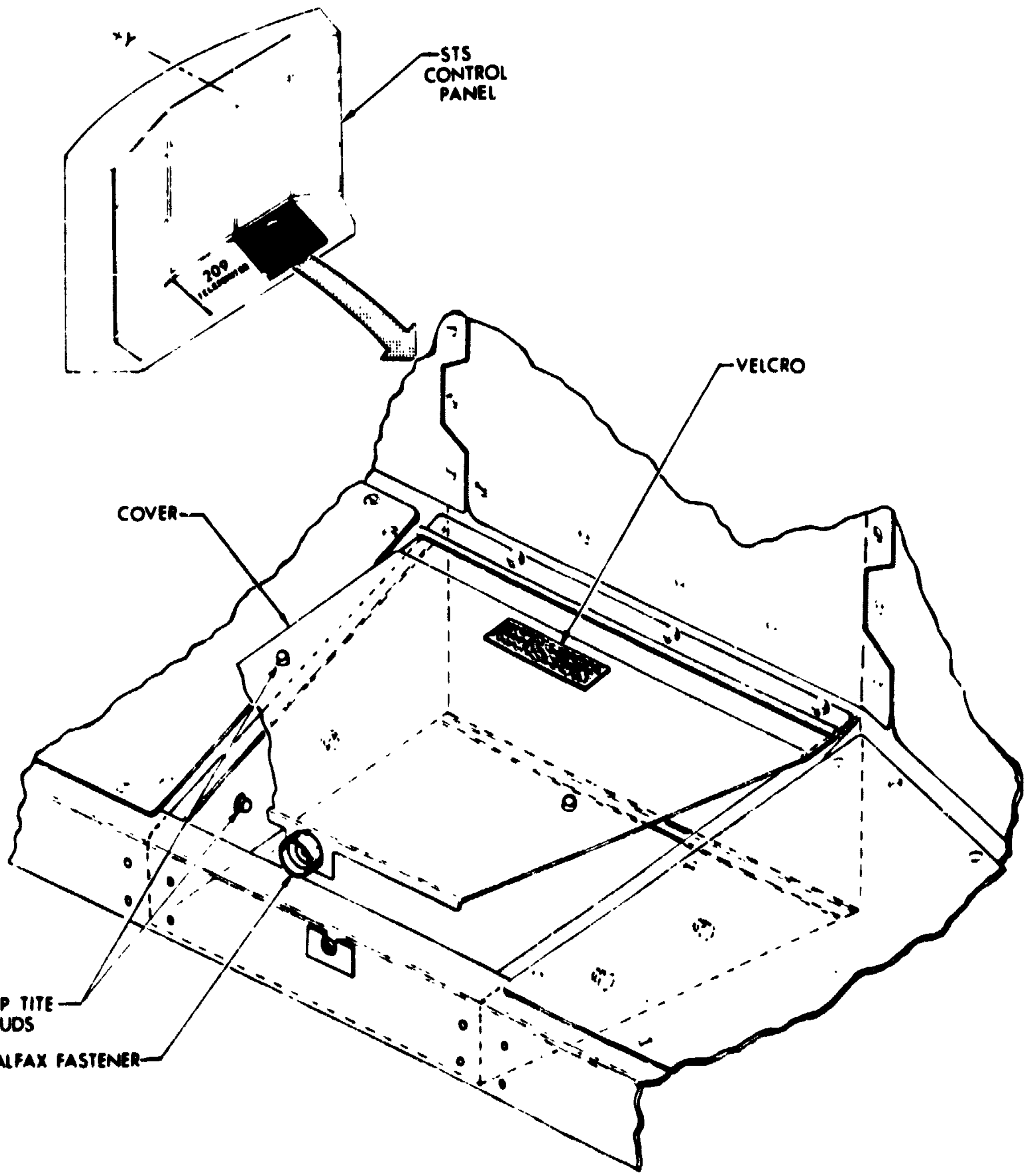


FIGURE 2.12-23 STOWAGE LOCATION M208

F. Stowage Locker M301 - This locker consisted of two compartments separated by an inner door (see Figure 2.12-24). One compartment contained 120 spare ten-watt light bulbs and 24 spare 20-watt light bulbs. The second compartment stowed inlet and outlet, active and passive $PPCO_2$ cartridges and PPO_2 sensors. All components were restrained by Mosite rubber; the door was held closed by Calfax fasteners. If required, the entire container could be removed and relocated.

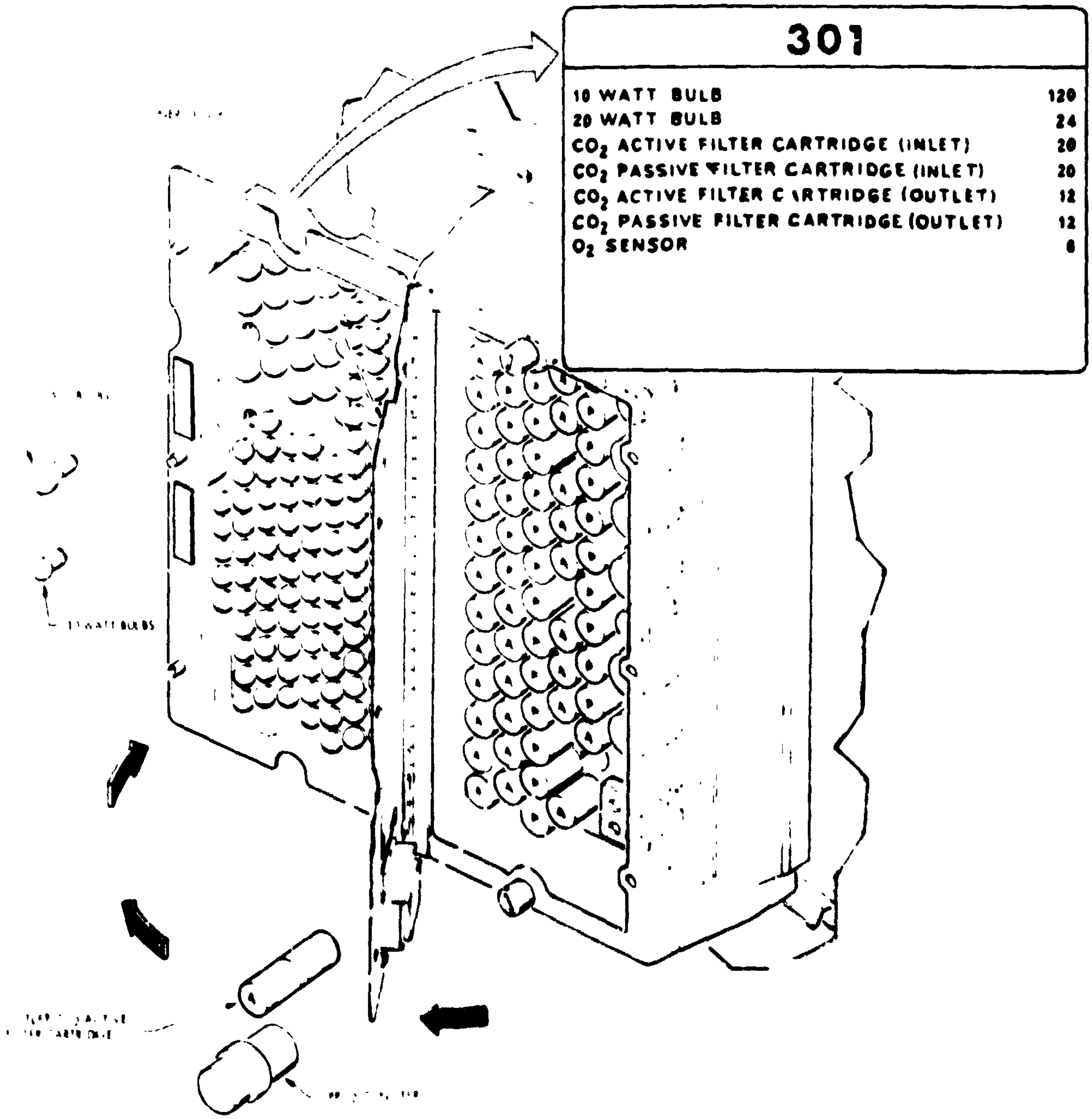


FIGURE 2.12-24 STOWAGE LOCKER M301

G. Stowage Location M303 - This location was assigned to the ECS return duct. Two plates, used to block the ECS supply and return ducts during EVA, were stowed at this location for launch, as shown in Figure 2.12-25.

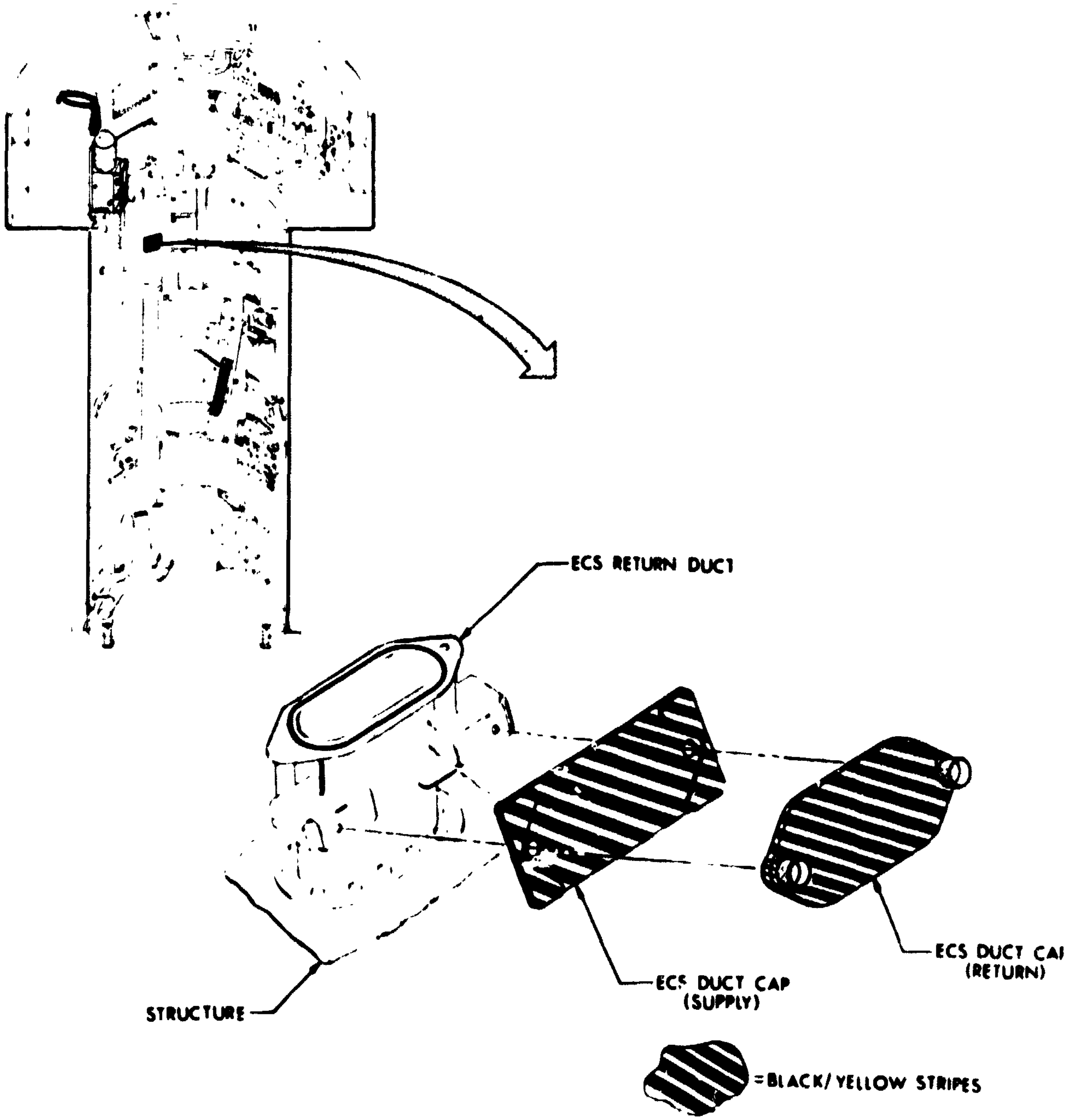


FIGURE 2.12-25 STOWAGE LOCATION M303

H. Stowage Locker M305 - The stowage location shown in Figure 2.12-26 was assigned to the locker which contained two EVA/IVA Coolant/Gas Separators and one Digital Display Unit.

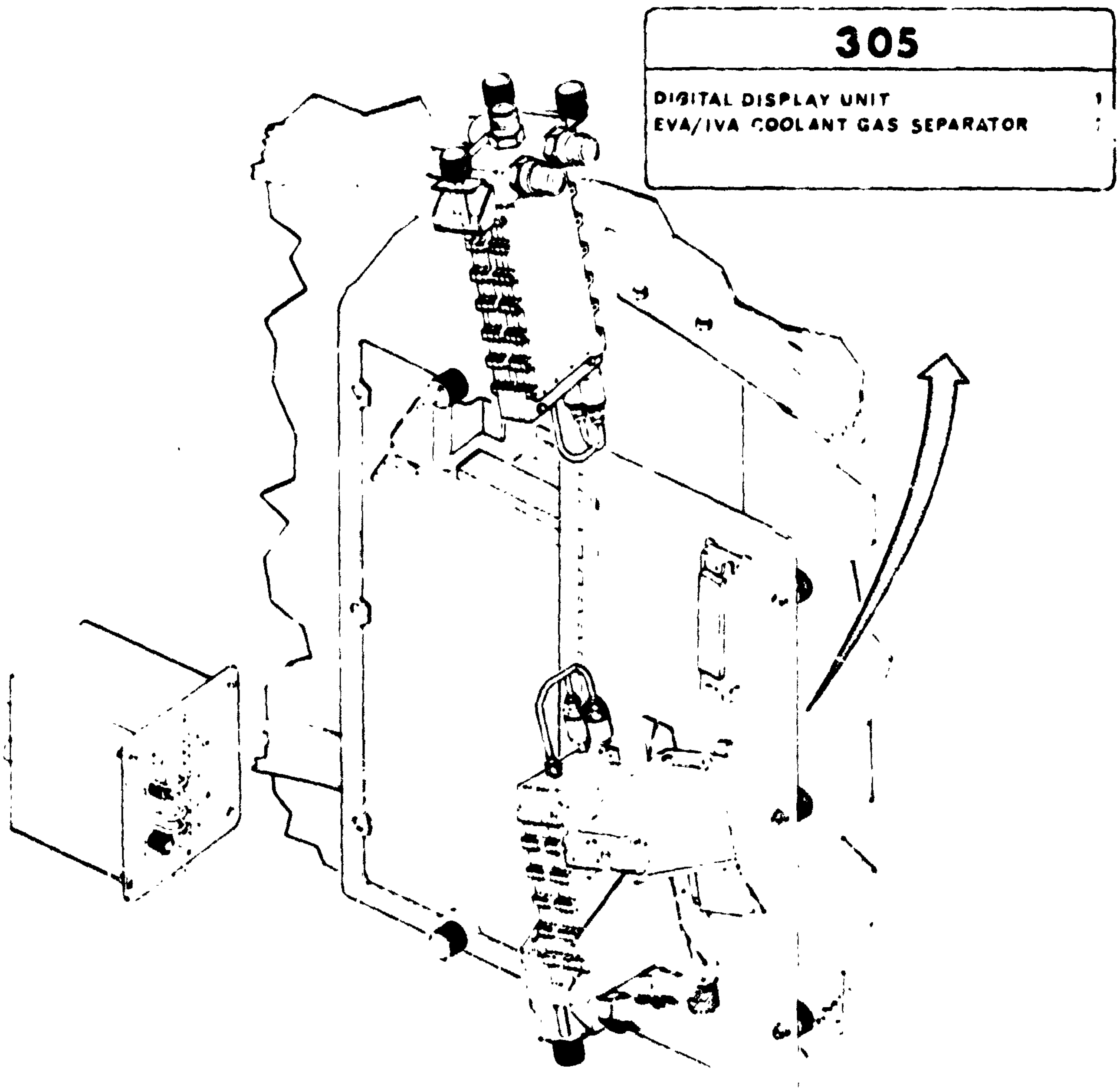


FIGURE 2.12-26 STOWAGE LOCKER M305

I. Stowage Location M307 - This location was assigned to the launch location of an emergency comm plug. It was on the underside of the Tape Recorder Module Cover.

J. Stowage Locations M308 and M313 - The stowage locations shown in Figure 2.12-27 were assigned to two locations in the lock compartment. Two AM Tape Recorders were launch stowed in each of these locations. During SL-2 activation, the tape recorders were moved to locker 438 in the OWS.

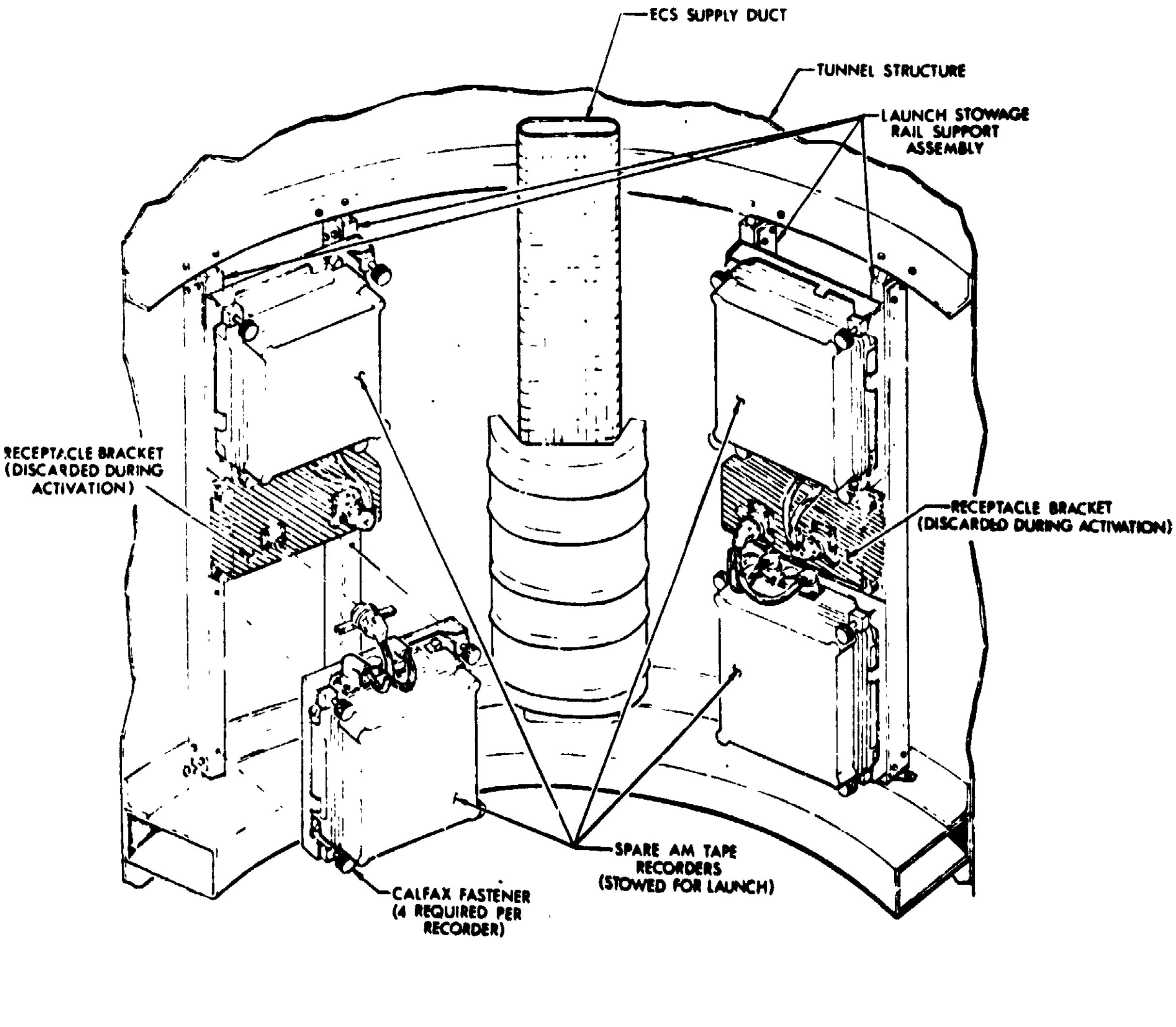


FIGURE 2.12-27 STOWAGE LOCATIONS M308 AND M313

K. Stowage Locations M310 and M311 - These stowage locations were assigned to the two Life Support Umbilicals (LSU's) and their respective covers, see Figure 2.12-28. When the LSU's were used during EVA's, the covers were stowed at locations M314 and M315 in the Aft Compartment.

The LSU's were faked in spheres, which were external to the tunnel wall, in a manner to allow an astronaut to pull out a desired amount of one end. The cover was used to cover the sphere opening and mechanically restrain the ends of the LSU's when stowed.

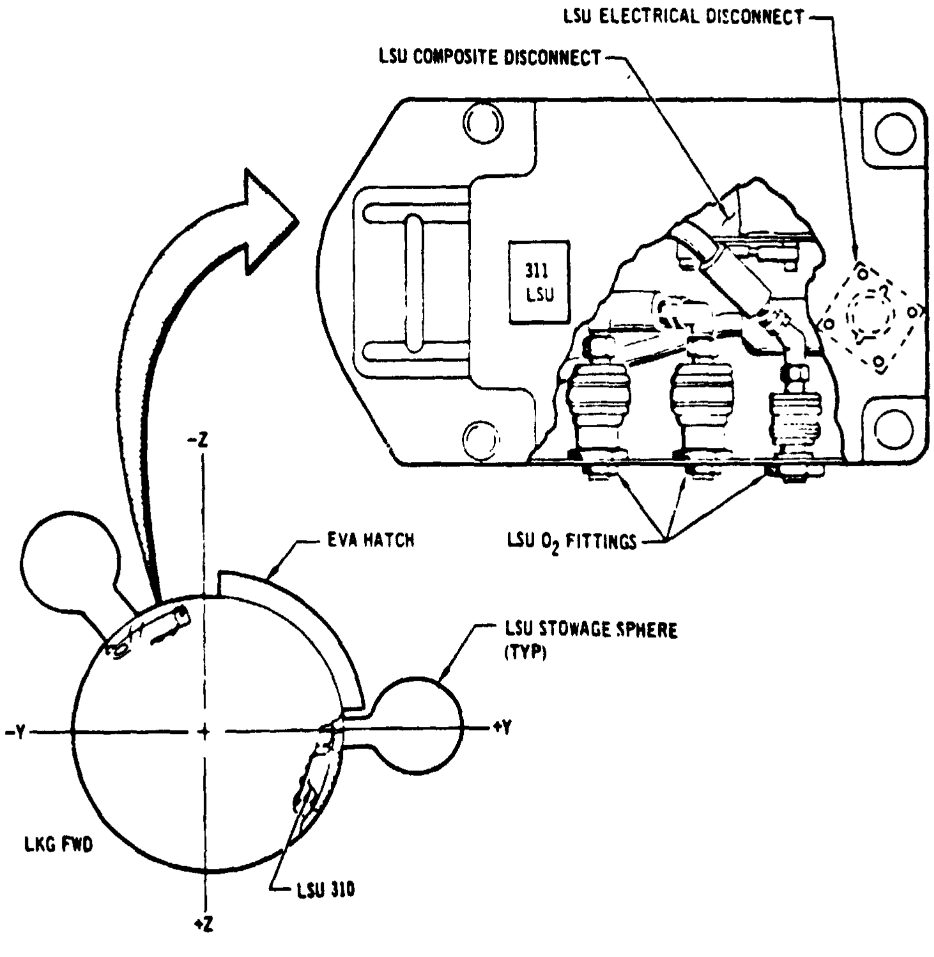


FIGURE 2.12-28 STOWAGE LOCATIONS M310 AND M311

L. Stowage Location M326 - This location was assigned to the OWS Heat Exchanger Module door in the Aft Compartment. A vent plate assembly, which normally covered an opening in the OWS Supply Duct, was stowed at this location, as shown in Figure 2.12-29, when the OWS drag-in duct was installed between the AM and OWS.

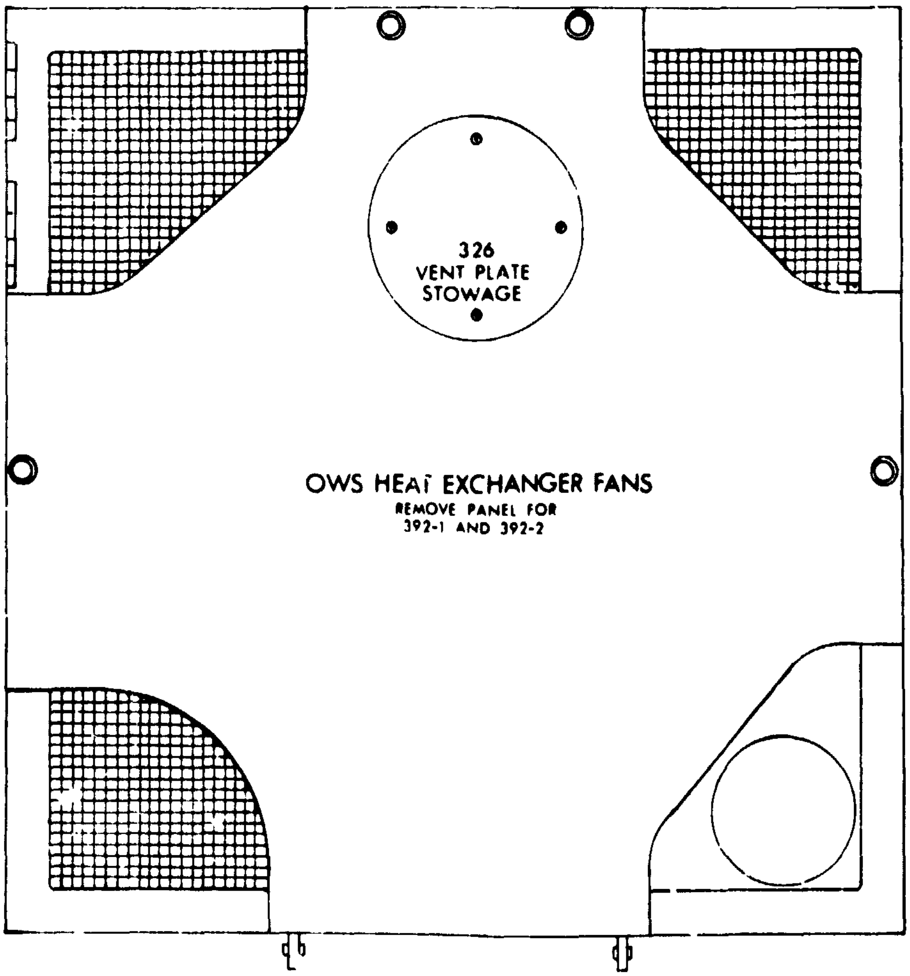


FIGURE 2.12-29 STOWAGE LOCATION M326

M. Film Transfer Boom/Hooks - As shown in Figure 2.12-30, in the EVA Quadrant (-Y to -Z) of the FAS area, one spare Film Transfer Boom (FTB) and three Boom hooks were installed. During the first EVA two of the hooks were installed on the two operable FTB's. The FTB stowed for launch and the third boom hook were backups to the two operational FTB's.

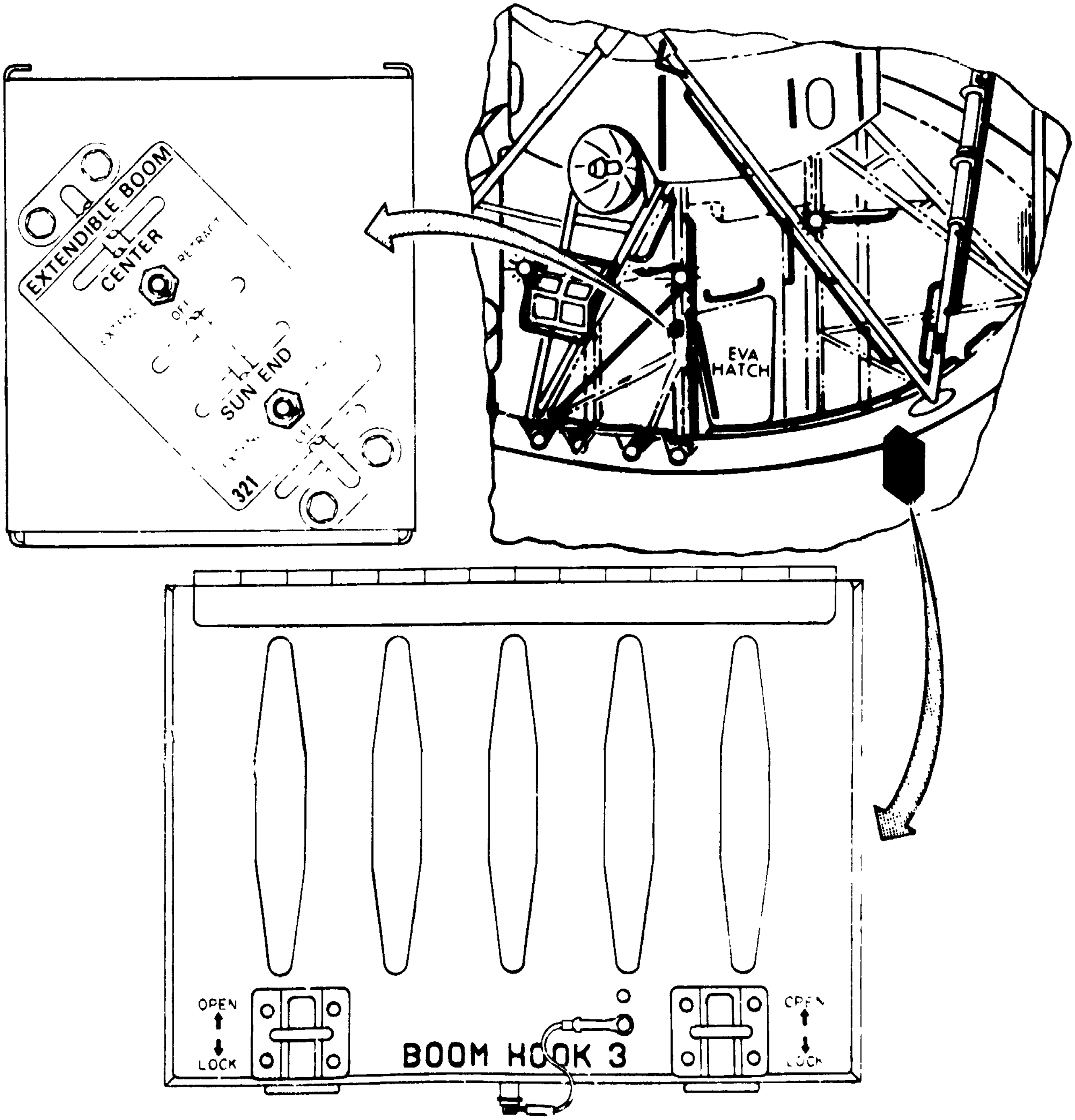


FIGURE 2.12-30 FILM TRANSFER BOOM/HOOK STOWAGE (SHEET 1 OF 2)

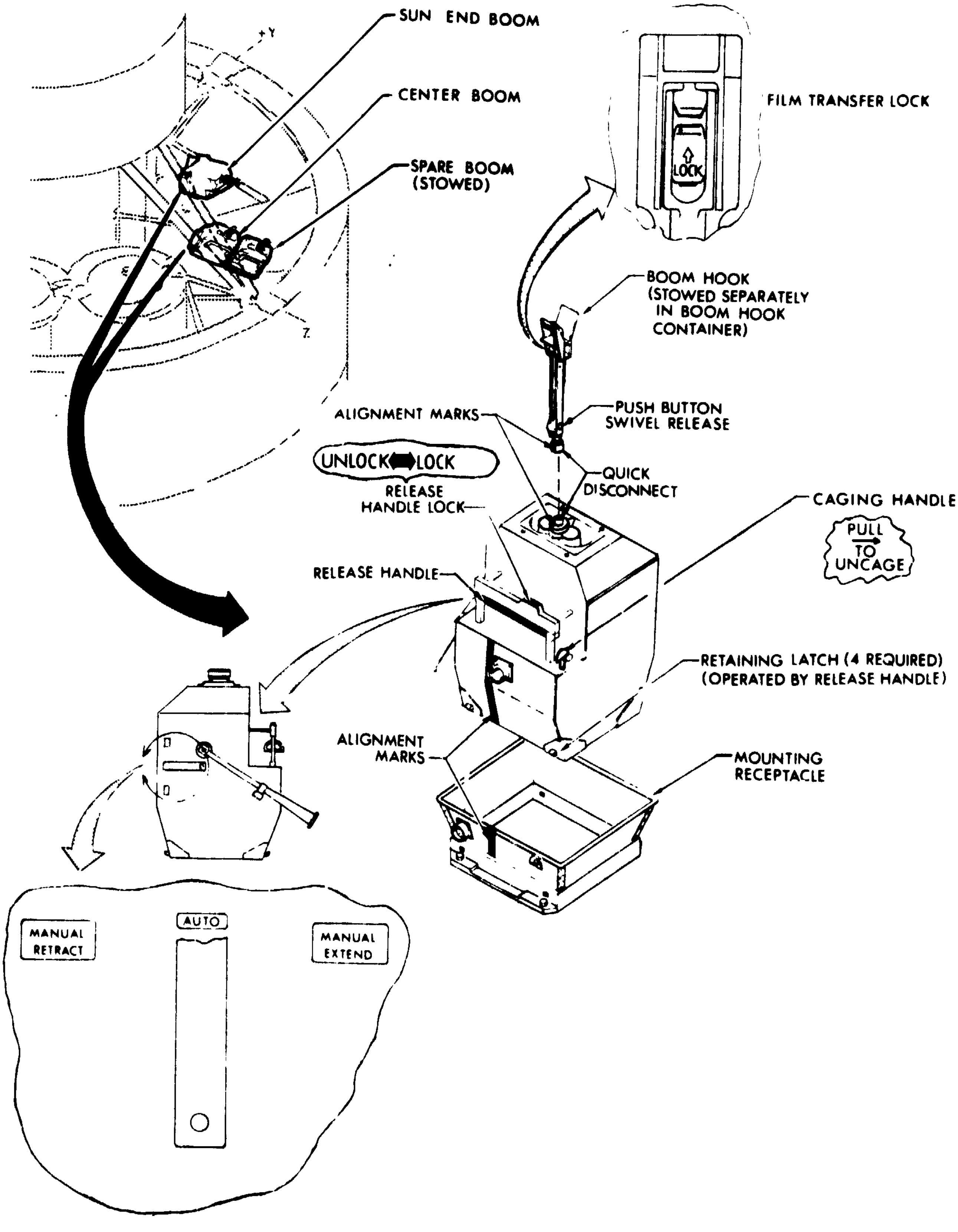


FIGURE 2.12-30 FILM TRANSFER BOOM/HOOK STOWAGE (SHEET 2 OF 2)

2.12.6.3 Customer Interface and Control

During the design phase of the Skylab Program, control of stowage aboard each module was maintained through the "Skylab Stowage List." This document was utilized by all contractors to define quantity, size, and stowage location of all stowage items to be launched.

Changes to the stowage list were submitted on a "Preliminary Stowage List Change Notice" (PSLCN) via an "Engineering Change Proposal" (ECP). In the same time frame as ECP submittal, the PSLCN was submitted to the "Stowage Coordination Working Group" (SCWG). The SCWG held semi-monthly meetings with the meeting location alternating between MSFC and JSC until January 1973. These meetings included personnel from MSFC, JSC, KSC, and all involved contractors. PSLCN's were discussed and changed as necessary before approval by the SCWG and CCBD. After January 1973, changes were coordinated via telecon with NASA personnel assigned to KSC.

2.12.6.4 Testing

Testing performed on stowage hardware consisted of: Acceptance Test Procedure (ATP), Preinstallation Acceptance (PIA), Bench Review, Crew Compartment Fit and Function (C^2F^2), Altitude Chamber Test, and Fit Checks. The ATP and PIA tests are the same as for launch installed components of the same hardware.

A Bench Review was conducted prior to C^2F^2. At this time, all available stowage items were laid out on tables. Then astronauts examined the items to get a better understanding of what each item was and how it was stowed. All problems found during Bench Review, i.e., the Teleprinter Spools would not fit in all the rolls of Teleprinter paper, were resolved prior to C^2F^2.

C^2F^2 consisted of a crew member(s) replacing an installed unit in the Airlock with a stowage replacement item. The system was then functioned to verify its operability. The objective of this test was to verify that in-flight maintenance tasks could be performed and that designated spare units would function when connected to the Airlock Systems.

Fit checks consisted of installing an item of flight stowage in its use location in the Airlock Module. These were not necessarily performed by Astronauts. These tests were performed to insure that a representative sample of each spare would fit in its use location.

During the Altitude Chamber Test, tests on the individual stowage containers revealed a potential problem. When Mosites, a closed cell foam, was exposed to a partial vacuum, it expanded. This resulted in high retention forces on stowage items and in higher forces being required to close covers on foam lined containers. This problem was resolved by using thinner Mosites and careful tolerance control.

A fit check matrix was used to verify that all stowage items had been fitted to all of its mating equipment. As stowage items were fit checked in their use location, the appropriate block in the matrix was stamped by quality assurance.

At the time of AM shipping to KSC, the fit check matrix, due to unavailability of some hardware, was not complete. As this hardware became available at KSC, the fit check was completed and certified. At SL-1 launch, all AM stowed items had been fit checked and verified.

2.12.6.5 Conclusions and Recommendations

A. Stowage items should be identified by S/N as soon as the proper quantity is available and usage should be rigidly controlled.
B. A complete set of flight representative tools should be obtained as soon as possible.
C. All stowage items should be accompanied by system log cards (SCL) that are used to record designated usage, fit and function history and handling/usage history
D. All stowage items, including stowage spare or equivalent items, should be shipped separately from the vehicle and should be treated as flight crew hardware, i.e., accompanied by all necessary paperwork.
E. All crew removable items not on the stowage list should be identified as controlled hardware and handled in same manner as stowage items.
F. The stowage fit check matrix should identify the test procedure utilized to perform the fit check.

2.13 CRUEW TRAINERS

Three trainers, the NASA Trainer, the Zero-G Trainer, and the Neutral Buoyancy Trainer, were designed and fabricated by MDAC-E for engineering evaluation and crew training.

In addition to the three trainers, the STA-3 vehicle, after completion of cluster acoustic and dynamics testing at JSC, was converted for Skylab Systems Integration Equipment (SSIE) usage at MSFC.

2.13.1 NASA Trainer

2.13.1.1 Design Description

The initial concept of the NASA Trainer (NT) was a full sized model of the early Airlock which consisted of a tunnel section, trusses and the "retro" adapter from the Gemini spacecraft. In addition, a simulated S-IVB hatch and portion of the dome were included.

External equipment consisted mainly of electronic modules, cryogenic bottles, relay panels and two telescoping beams with hoses to transfer cryogenics from the bottles to the fuel cells in the Command Service Module. See Figure 2.13-1.

As changes occurred in the vehicle configuration, the trainer was updated to reflect these changes. The major changes consisted of replacing the retro adapter with the STS, and the addition of the FAS, DA and a portion of the Payload Shroud. (Due to the large diameter of the FAS, it was constructed in four quadrants for shipping purposes).

The NASA Trainer as delivered (See Figure 2.13-2) was a high fidelity vehicle consisting of:

- Tunnel Section.
- Structural Transition Section (STS).
- Four Trusses.
- Fixed Airlock Shroud (FAS).
- ATM Deployment Assembly (DA).

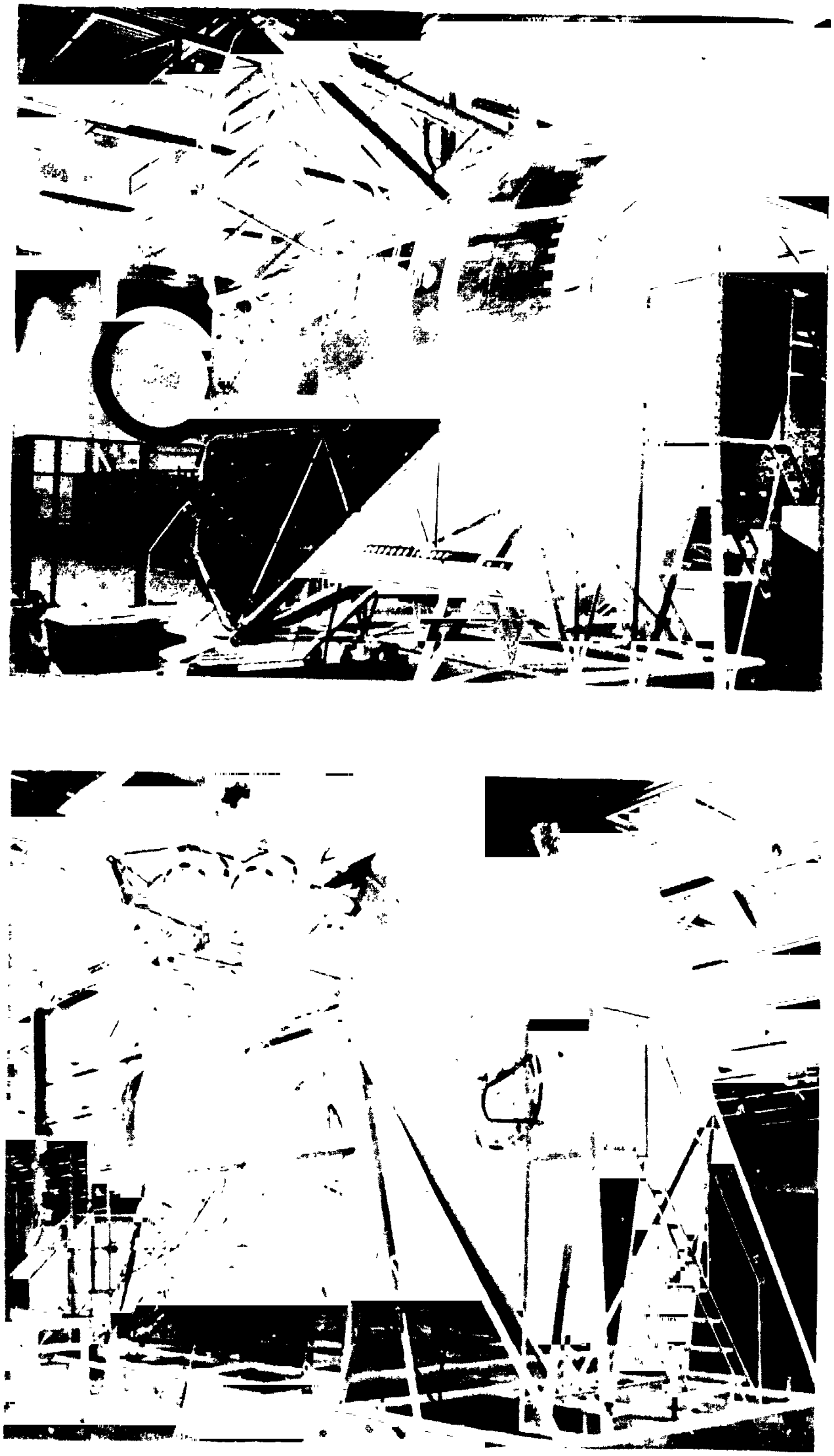


FIGURE 2.13–1 EARLY AIRLOCK TRAINER

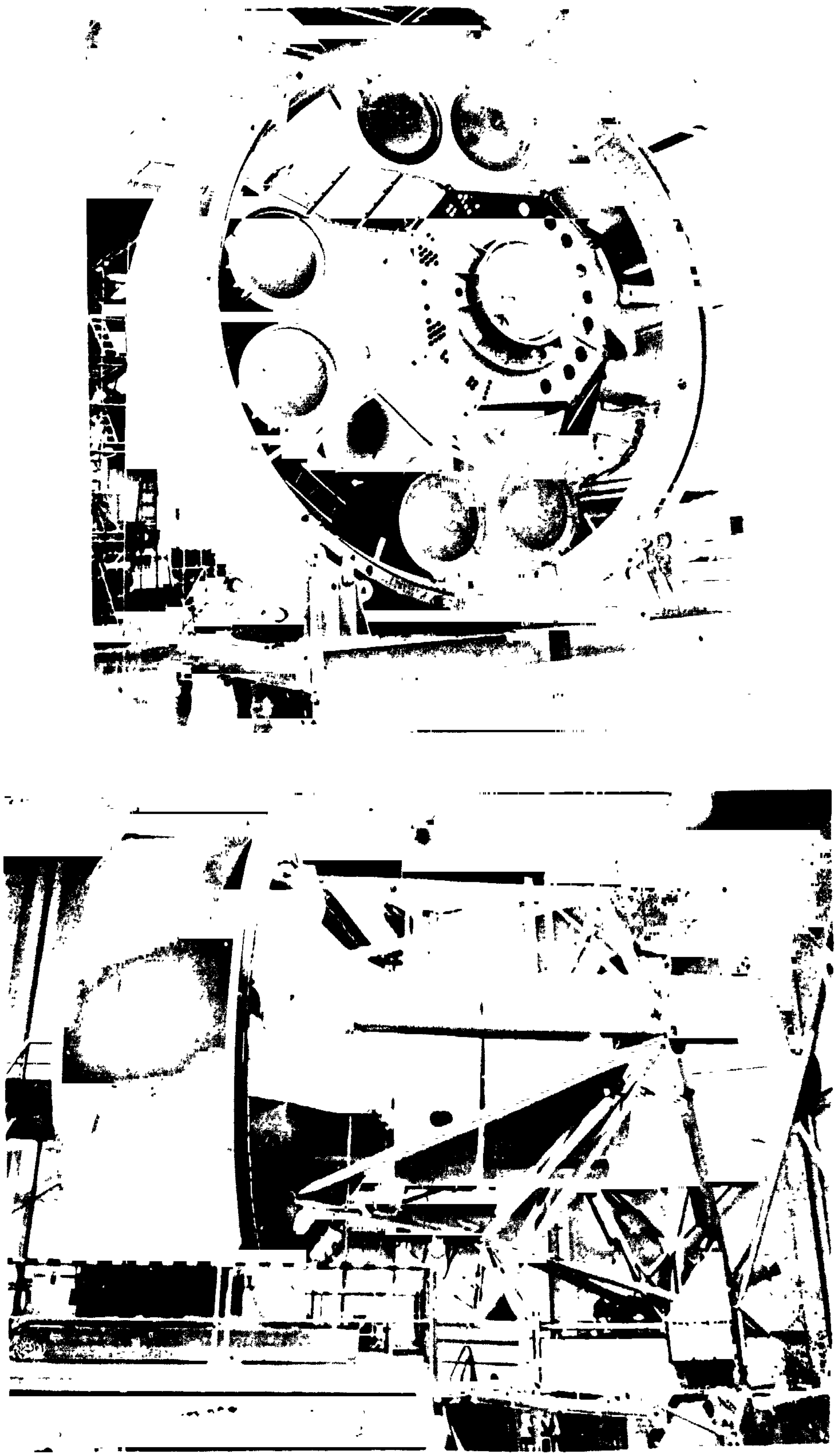


FIGURE 2.13-2 THE NASA TRAINER

- Segment of OWS Dome.
- Portion of Payload Shroud (PS).
- Dolly Capable of Rotating 360°.

Internal and external equipments were simulated to provide high fidelity installations in areas affecting crew operations.

Connections for air, water and communications were provided to allow crew members to train in pressurized suits. Wire bundles were simulated in areas where they were visible to crew members. Where wire bundles were covered by debris covers only the debris covers were simulated.

All operable controls, switches, dials, connectors, electrical interconnections and terminations were actual or simulated to evaluate design and to facilitate training in the performance of these tasks. All hatches and other operating mechanisms had representative forces and operating configurations. The STS bulkhead between Stations 153.00 and 157.00 was divided into two separate bulkheads, each two inches thick. The purpose for this was to be able to locate the STS on the tunnel section or to mount it separately on the MMC constructed MDA trainer.

Two identical External Trainer Base Connector Panel Consoles (one for the STS and one for the Trainer Tunnel Section to permit independent operation) were furnished to provide electrical power, suit cooling, breathing air, caution and warning tones, communications, and the necessary plumbing and wiring jumper cables to each of the two training units. See Figure 2.13-3.

Initially two support stands were provided. One was used to support the tunnel, trusses, STS and 3 quadrants of the FAS. The other stand supported the partial S-IVB dome. See Figure 2.13-4. In order to provide greater training access to external equipment and to provide for zero-g simulation in a one-g environment, a new support stand which had the capability of rolling the trainer 360° about the X-axis in the horizontal position, was designed and fabricated. The original support stand was utilized as a shipping dolly for the tunnel section with trusses attached.

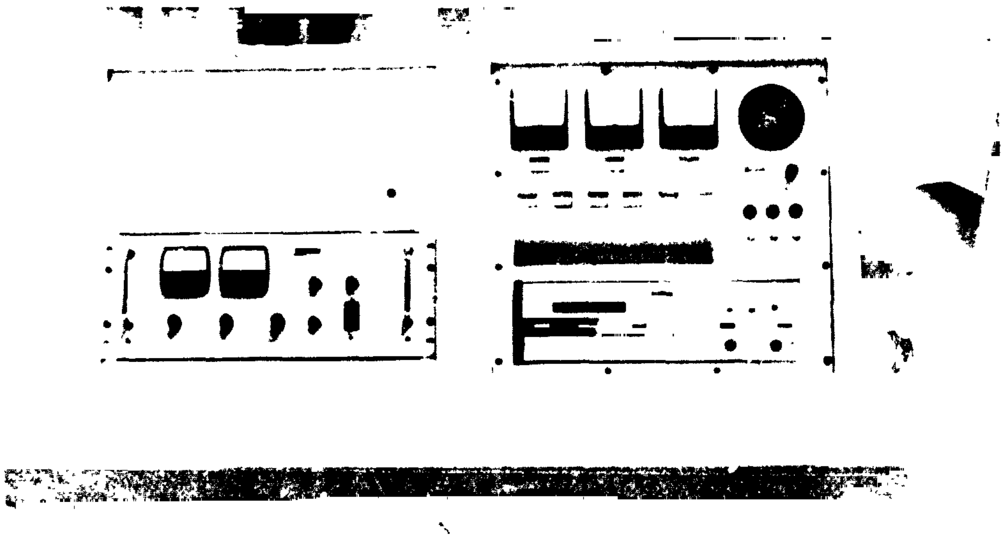


FIGURE 2.13-3 NASA TRAINER CONNECTOR PANEL

FIGURE 2.13-4 NASA TRAINER – INITIAL SUPPORT STAND

Prior to shipment of the NASA Trainer, it was used at MDAC-E for the following purposes:

- Contractor Engineering Design Evaluation.
- Manufacturing Procedures Evaluation.
- Customer (NASA) Evaluation.

In addition, periodic flight crew walk-through reviews were conducted to checkout:

- Adequacy of Lighting.
- Planned operating procedures.
- Accessibility and operation of crew operated equipment.
- Placement, configuration and quantity of handrails and foot restraints.

In April 1970, MDAC-E was directed by NASA (CCP 060) to provide parts and personnel for installation of the following:

- FAS internal structure.
- FAS crew workstations and foot restraints.
- ATM film cassettes and stowage shoes.
- ATM Film Transfer devices and control box.
- Handrails and handholds.
- Umbilical clips and temporary stowage hook.
- EVA lighting.

In August 1971 MDAC-E was directed by NASA (CCP 125) to modify the 17-foot support stand for supporting the NASA (one-g) Airlock trainer and dolly at JSC-Houston. This required structural beef-up, addition of removable catwalks with handrails, dismantling of stand at MSFC for shipment, and reassembly at JSC, in a very limited time span. See Figure 2.13-5.

The NASA Trainer was delivered to JSC in October 1971. A set-up time of four weeks was required at JSC, with final electrical checkout accomplished in the following two weeks. This set up activity included the following:

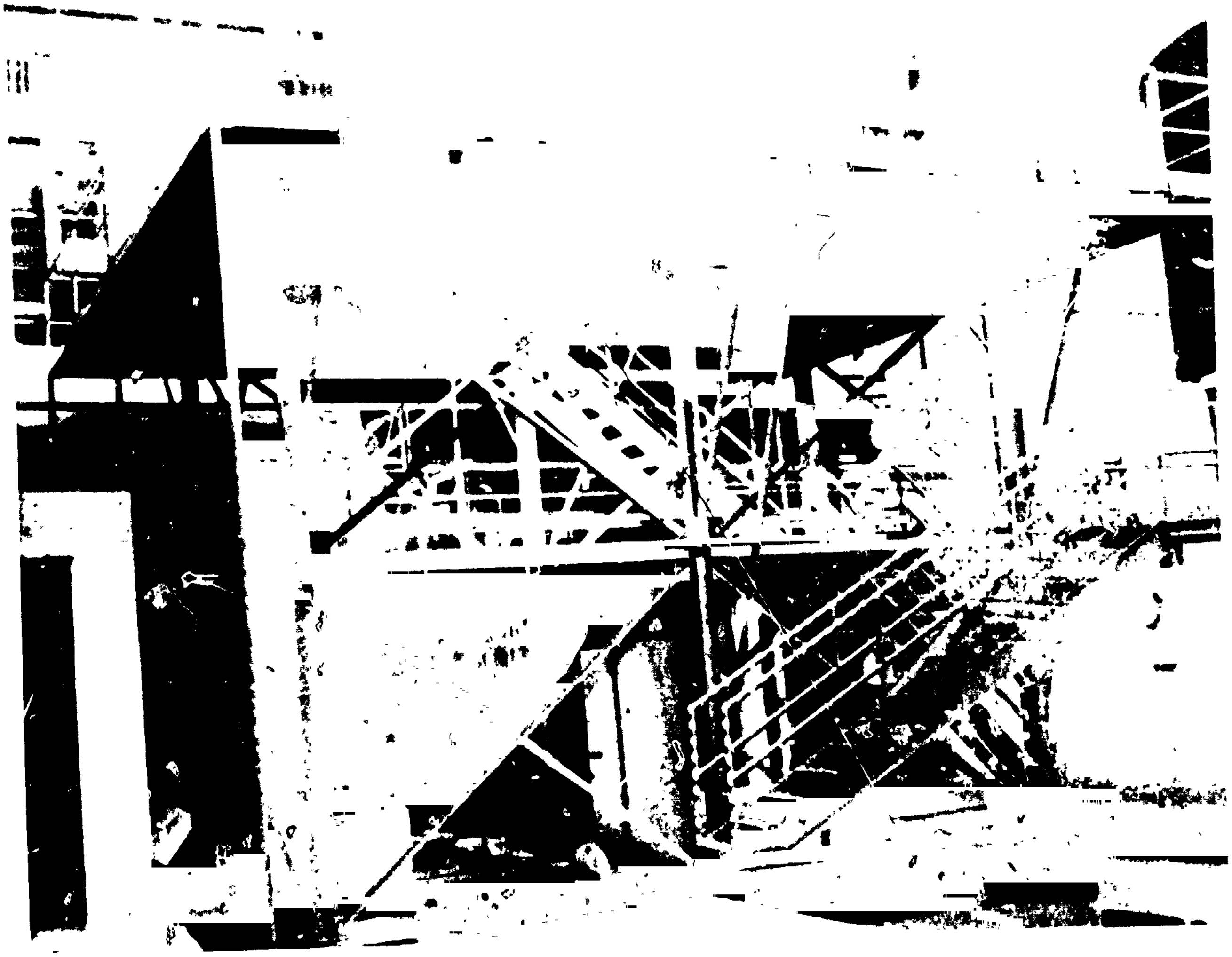


FIGURE 2.13-5 EVA STAND MODIFICATIONS

A. Mounting the Trainer on the modified 17-foot high stand which was required so that the ATM could be positioned at floor level with the DA deployed. Refer to Figure 2.13-6.

B. Reassembly of a complete NASA Trainer.

C. Hook up and checkout of consoles:

- Electrical.
- Air - for IVA & EVA panels for suited work.
- Water - IVA & EVA panels for suit cooling.
- Communications.

2.13.1.2 Usage at JSC

The NASA Trainer was used by the astronauts for training involved with their mission. This training included the normal mission tasks and contingency activities.

A. Procedure writers used it to set up step by step procedures for work by the astronauts.

B. Instructors used it for familiarization of vehicle and training procedure prior to astronaut training.

C. It was used for mission support to assist in solving flight anomalies.

The NASA Trainer was used by NASA personnel as a mock-up to fit new experiments, to establish new mission criteria, and as a familiarization unit for officials and visiting dignitaries as well as the general public who had a vital interest in Skylab.

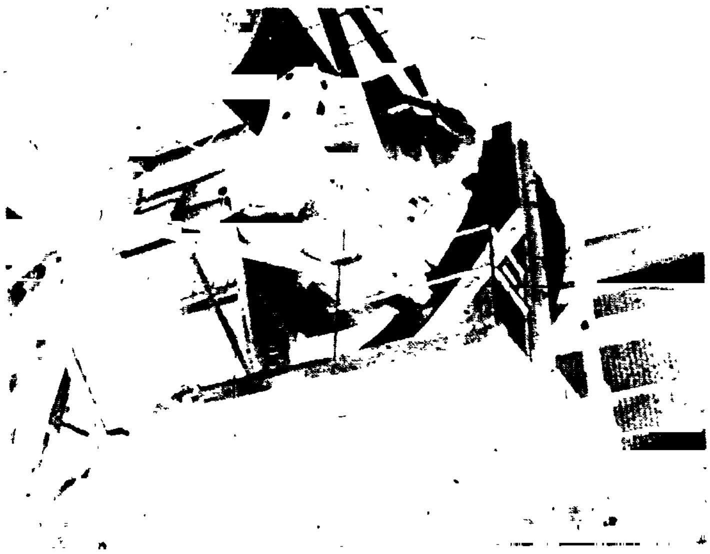


FIGURE 2.13-6 EVA DEVELOPMENT STAND AT MSFC

2.13.1.3 Post Delivery Support

MDAC-E continued support of the NASA Trainer after delivery to incorporate modifications required to keep the trainer configuration compatible with the flight hardware. MDAC-E also provided routine maintenance required to keep the trainer fully operational.

A. Trainer Modification - All ECP and CCP's, as well as all other engineering changes were reviewed by the trainer engineering group. Any change which involved a direct interface, functionally or physically, with the astronauts, was incorporated on the trainer. During fourteen designated modification periods, MDAC-E manufacturing personnel were sent to JSC to install new hardware and modify existing hardware. A MDAC-E engineer was also in attendance during each modification period to provide on-site liaison. Modification work was controlled by manufacturing and engineering schedules and actual installation and modification was controlled by MDAC-E planning. Category II planning was prepared to provide step-by-step procedures for this activity.

   Modification and maintenance time scheduling was required to be sandwiched in and around training schedules. Sudden changes in training schedules required that modification work be stopped or changed. Second or third shift activity was required as training tended to overlap into the second shift. All work had to be scheduled to be finished in one work period so that training could continue the next day. After completion of a particular modification, an Installation Notice Card (INC) was completed. A brief description of the task and signatures verifying installations, inspection, and government acceptance were carried on the INC.

B. Maintenance - Extensive trainer usage required a normal amount of maintenance. Maintenance was accomplished by the same personnel who performed trainer modifications. Time was allocated during each of the modification periods for normal maintenance work, such as repainting, new lettering and decals, repair or replacement of damaged parts.

C. Mission Support - During the time trainers were used for mission support, MDAC-E resident engineers provided on site engineering support.

2.13.1.4 NASA Trainer Drawing System

The drawing system used to produce the NASA Trainer was a combination of the production drawing system and Trainer Preparation Sheets (TPS). This system allowed the use of available materials and hardware to expedite the manufacturing of the trainer, without conformance to flight quality requirements.

- Production drawings were used if that was the most economical method and time was not critical.
- Reproductions of production drawings, with trainer drawing numbers, allowed the use of less expensive materials and production methods. as well as elimination of quality requirements not applicable to a trainer.
- Special trainer drawings were prepared if changes to use a production part/assembly were so extensive that it was not cost effective to modify a production drawing.
- TPS's were used in conjunction with sketches, drawings, and other advance information to authorize the manufacture and allocation of trainer parts.
- The trainer engineering group provided direct support to the manufacturing effort to expedite the production and delivery of parts.
- A trainer log book was used to record on-the-floor engineering verbal instructions for manufacturing use; these instructions were later incorporated into the trainer drawings.

2.13.1.5 Conclusions and Recommendations

The NASA Trainer proved to be an extremely useful piece of hardware.

- Prior to delivery it was used to evaluate system designs and installations as well as all aspects of crew operations.
- After delivery it was used as the primary training device for each crew.
- During the mission it was used to support anomaly investigations and to verify proposed flight crew activity.

The system used by MDAC-E to design and produce the NASA Trainer was a modification of the flight hardware system and emphasized a much less formal drawing system and more on-the-floor engineering direction. This approach provided the capability to quickly react to system changes and to quickly verify new crew interfaces with a high fidelity system.

The same basic approach with some changes would be valuable on future MDAC-E trainer design and production efforts.

- Advance copies of new drawings and changes should be provided direct from all production design groups to trainer group; if applicable, trainer effectivity should be added prior to drawing release.
- A listing of available hardware not usable for flight, but satisfactory for trainer usage, should be maintained; both vendor items and MDAC-E manufactured items.
- A trainer parts coordinator should be assigned to track parts in the manufacturing and shipping cycles.
- Trainer prep sheets should be used to expedite procurement and manufacturing of trainer parts.
- A trainer log book should be used to record verbal instructions to manufacturing; all such instructions should be periodically incorporated into the trainer drawings.
- Equipment lockers should be provided in the trainer manufacturing area and the parts crib to keep trainer parts separate from flight hardware.

2.13.2 Zero-G Trainer

A zero-g evaluation was required of any pressure suited activity planned for small volumes or tight confines. The Zero-G Trainer was designed for installation on a USAF KC-135 aircraft to accomplish this evaluation and related EVA development exercises. Therefore it consisted of only the AM tunnel section and related equipment needed to perform these functions. Figure 2.13-7 shows internal and external views of the trainer. Design features of the Zero-G Trainer included:

- Flight quality hatches and mechanisms.
- All handholds, handrails and panel guards.
- Integral solid state communications provisions.
- Tunnel splice at Station 42.00 to facilitate loading through KC-135 cargo door.
- Special lighting for photography.
- Air bearing support stand for ease of movement to the aircraft floor attach points.
- Suit pressurization provisions.
- Special damper on EVA hatch (See Figure 2.13-8) to absorb 2-g aircraft pullout loads.
- LSU stowage/handling provisions.
- Trainer compliance with Zero-G aircraft load/safety factor.

Zero-g development testing was performed during parabolic flight path meneuvers on the USAF KC-135 aircraft. As a result of this testing:

- Hatch sizes and locations were deemed satisfactory.
- Lock compartment volume/size was deemed satisfactory for EVA operations.
- Internal hatch mechanisms were redesigned with improved overcenter action and feel.
- LSU handling/stowage features were developed.
- Handrail/handhold locations were defined.

After delivery, 17 June 1968, the trainer and zero-g testing was supported by MDAC-E engineering and manufacturing personnel as follows:

- ECP/CCP incorporation via modification kits to maintain a current configuration.
- Maintenance and repair as required.

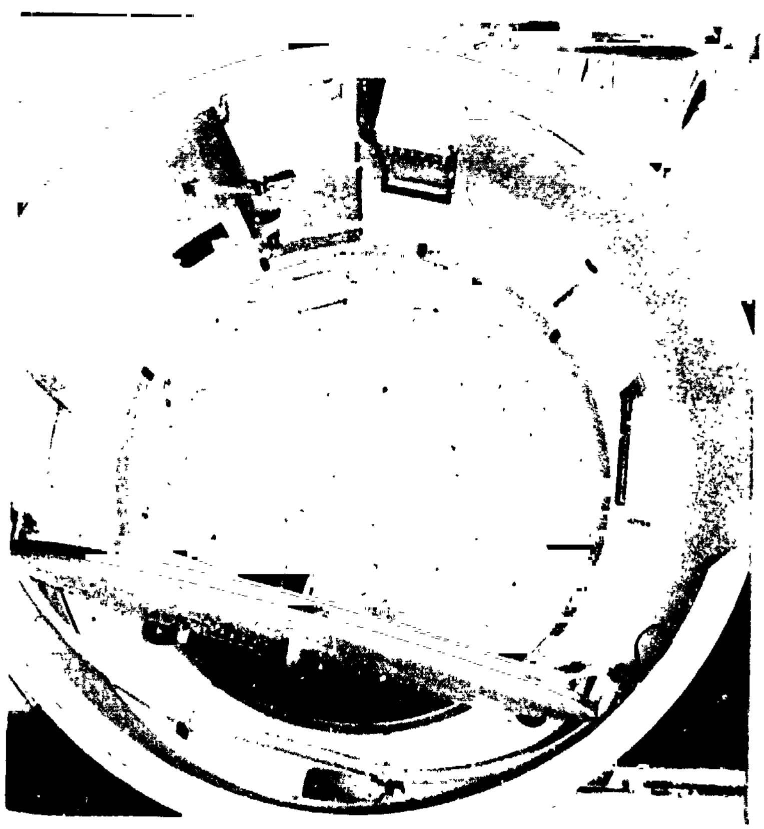


FIGURE 2.13–7 ZERO-G TRAINER

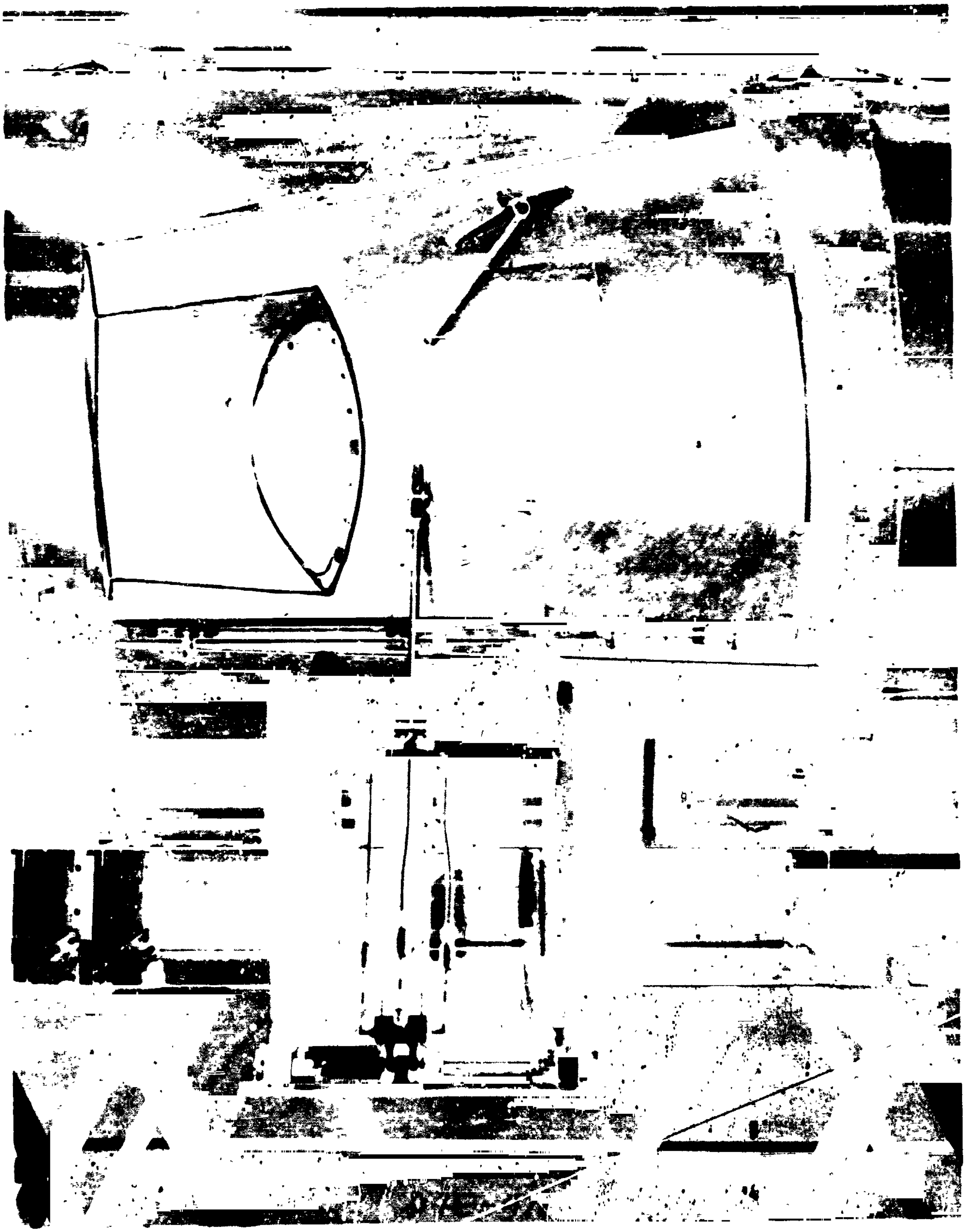


FIGURE 2.13-8 ZERO-G TRAINER – EVA HATCH DAMPER

- Pre and post zero-g flight inspection to insure proper functioning and aircraft installation.
- Zero-g inflight evaluation to assure a closely coordinated test program, and to assure design incorporation of test results.
- Incorporation of special trial or test installations for zero-g evaluation.

Zero-g flight development occurred primarily during the first year after trainer delivery. After contract transfer from JSC to MSFC (late 1969) the trainer was relocated to MSFC and used as a one-g EVA system development tool. In October 1971 this trainer was relocated from MSFC to JSC where one more zero-g training flight was accomplished. Thereafter, it was updated, maintained and used in conjunction with the STS and the MDA as a high fidelity one-g training unit. (See Figure 2.13-9.) In addition, the Airlock Zero-G Trainer was mounted by itself on a trunnion-type dolly that allowed the unit to be positioned vertically as well as horizontally, thereby permitting pre-EVA and post-EVA crew training to be conducted.

2.13.3 Neutral Buoyancy Trainer

2.13.3.1 Design Description

The original design of the Neutral Buoyancy Trainer (NBT) was a full size model of the Airlock, consisting of a tunnel section, 2 trusses (one on each side of the EVA hatch), a simulated Gemini "retro adapter", and a simulated section of the S-IVB dome and Spacecraft Launch Adapter (SLA). The trainer was constructed from expanded metal to facilitate quick immersion and drainage; and to facilitate underwater monitoring for crew training. Holes were drilled where expanded metal could not be utilized. Cryogenic bottles were simulated and installed externally on the upper truss.

The assembly was mounted on a small, wooden, fixed position dolly which was also used for shipment to JSC in December, 1966. See Figure 2.13-10.

After NBT delivery, major design changes in the Airlock Module required recalling the NBT, in May 1967, for extensive rework and updating.

FIGURE 2.13-9 ZERO-G TRAINER USED AS A HIGH FIDELITY ONE-G TRAINER

FIGURE 2.13-10 ORIGINAL NEUTRAL BUOYANCY TRAINER

The update consisted primarily of replacing the "retro adapter" with the Structural Transition Section, removing the cryogenic bottles, and replacing the original dolly with two all metal dollies; one for the tunnel and one for the STS. These dollies had the capability of rolling the counterbalanced trainer 360° about the horizontal axis and being able to lock in any position (See Figure 2.13-11). An escape hatch was added to the tunnel similar to the two in the STS. Simulated internal equipments such as ducts, lights, and instrument panels were installed. The envelopes of internal and external equipments were installed in areas that affected EVA and crew operation (Figure 2.13-12).

2.13.3.2 Usage at JSC

In August, 1967, the modified Neutral Buoyancy Trainer was redelivered to JSC and installed in the Water Immersion Facility (WIF) in Building 5 as shown in Figure 2.13-13.

The following parts were designed, fabricated and installed on the trainer for crew evaluation.

- Handrails of various lengths, heights, cross sections, and contours, located in various places on trainer.
- Cabinets of various sizes and at various locations.
- Thermal curtain structural door configuration (later deleted).
- Rotatable EVA foot restraint platform (later deleted).
- EVA hatch hold-open devices.
- EVA hatch open-closed restraint latch.
- Lithium hydroxide cannister stowage in STS (later deleted).
- Trash disposal containers and stowage compartment within No. 4 Truss (later deleted).
- Umbilical clips and their location for EVA.
- Internal hatch restraint devices.

In early 1969, the Neutral Buoyancy Trainer was shipped to MSFC where a much larger WIF was available. This move was required to accommodate the much larger size of the "dry" launch configuration.

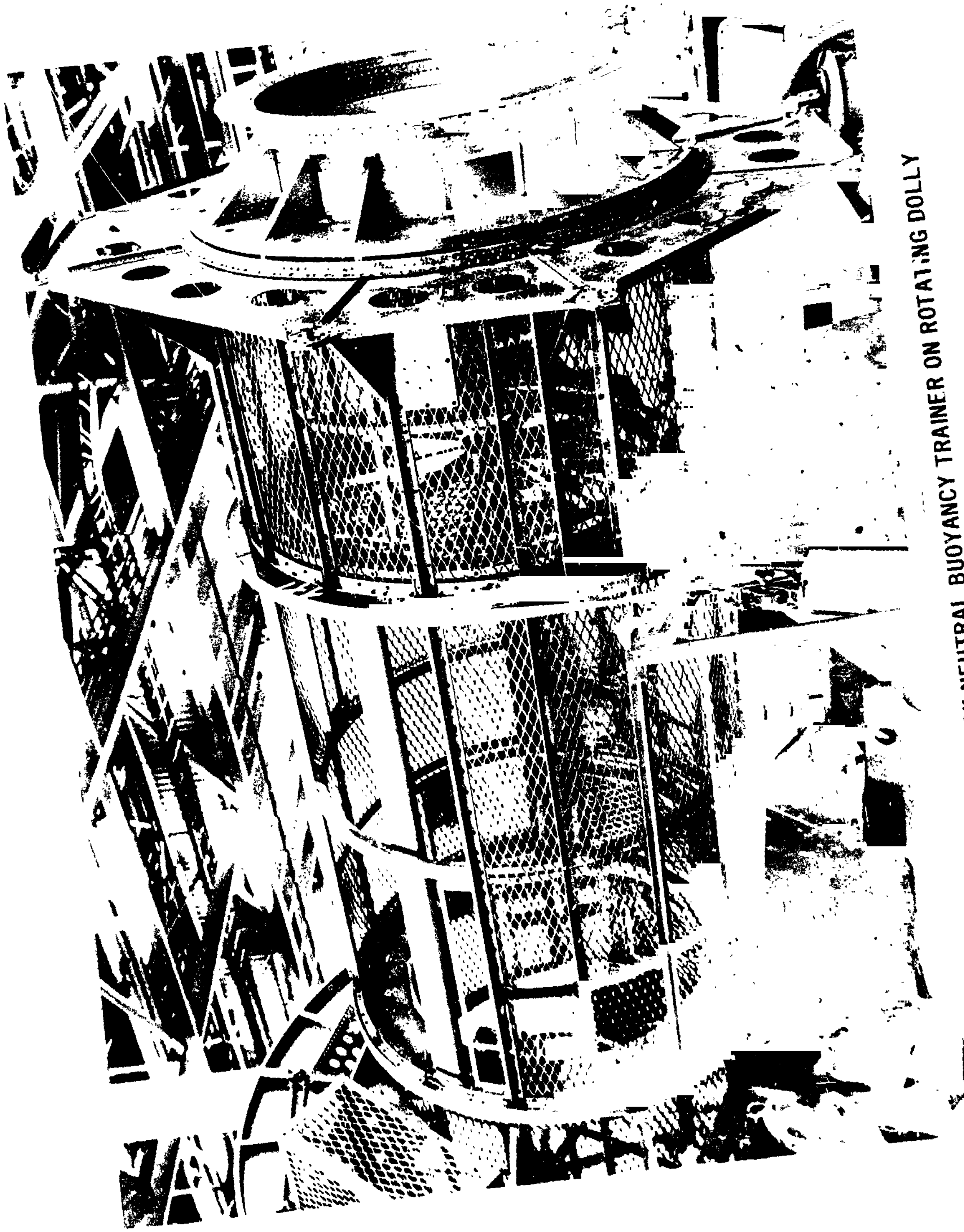
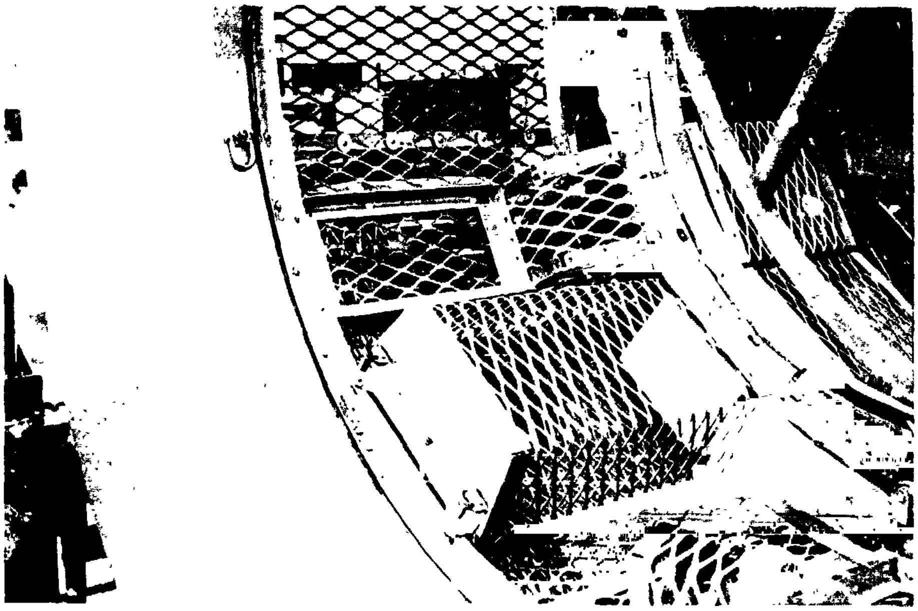
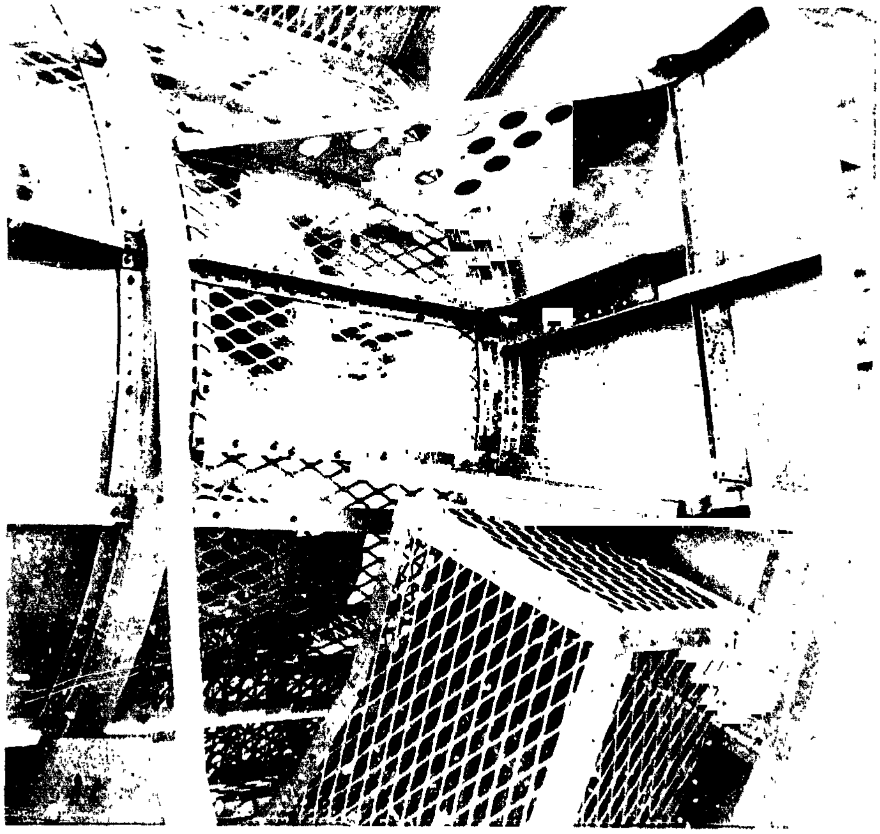


FIGURE 2.13-11 AIRLOCK NEUTRAL BUOYANCY TRAINER ON ROTATING DOLLY



Internal Equipment Simulation



External Equipment Simulation

FIGURE 2.13-12 NEUTRAL BUOYANCY TRAINER

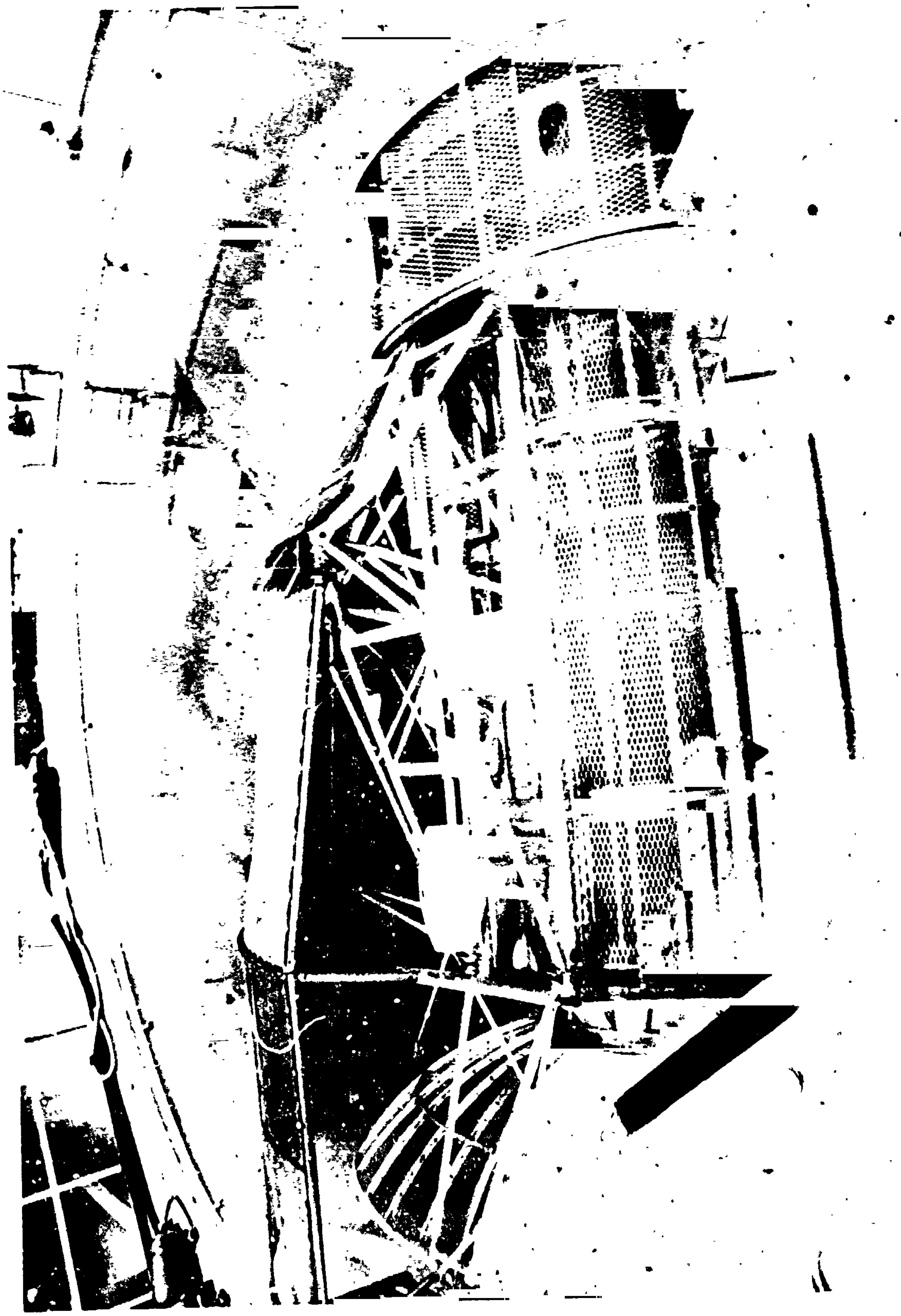


FIGURE 2.13-13 NEUTRAL BUOYANCY TRAINER IN JSC FACILITY

2.13.3.3 Usage at MSFC - Training

In the fall of 1969, MDAC-E was requested to provide engineering coordination and drawings, and to supply the more complicated parts to bring the trainer up to date for continuation of developmental work and crew orientation at MSFC. Later, per CCP 47, Item 29, MDAC-E was given complete responsibility for documentation, hardware, updating, and maintenance. A model of the updated configuration is shown in Figure 2.13-14. The changes necessitated approximately two weekly update periods each month. The following changes were made:

- Lock compartment control and EVA panel update (ECP 135).
- Fabrication and installation of the ATM Deployment Assembly, including attached equipment such as lights, wiring covers, handrails, junction boxes, etc., per CCP 96.
- Fabrication and installation of FAS internal structure and equipment in the EVA quadrant, including dummy and air-operated ATM film transfer booms per CCP 96.
- Complete overhaul of Airlock trusses, STS and tunnel section, i.e.; removal and refurbishment or replacement of all equipment, handrails and any deteriorated structure, in addition to updating, lubricating and re-rigging the EVA hatch and both internal hatches.

The Skylab "Dry Launch" concept initiated the need for many design changes which required very close coordiantion and interface with NASA personnel by MDAC-E scuba-diving engineers during this period.

Crew mission training, shown in Figure 2.13-15, began in January 1972, necessitating MDAC-E personnel support during crew training periods in addition to the usual update and maintenance work. Entailed in training were such items as:

- Evaluation of EVA retrieval procedures for film packages.
- Checkout of boom operation procedures.
- Evaluation of EVA egress and ingress procedures.
- Evaluation of EVA work area utility.

FIGURE 2.13-14 MODEL OF NEUTRAL BUOYANCY TRAINER IN MSFC FACILITY

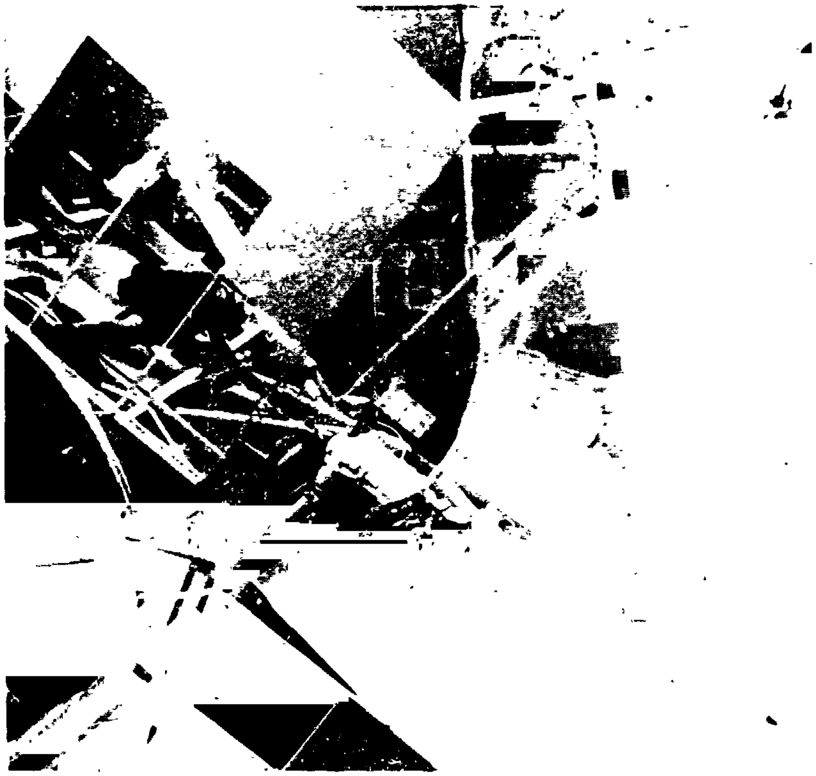


FIGURE 2.13-15 NEUTRAL BUOYANCY TRAINER - CREW TRAINING

During this time, five 3-man crews were trained for EVA. WIF training capacity is two suited crewmen, so crew members were rotated through the facility. All training periods were covered by appropriate MDAC-E personnel.

After training began, many changes were incorporated on the flight article due to problems uncovered in the WIF. These included:

- Adding identification numbers to all EVA handrails.
- Redesigning internal hatch latching mechanism to prevent "lock-out".
- Redesigning clothesline stowage boxes and packing procedures.
- Relocating EVA hardware; i.e., clothesline clips, DAC location, etc.

2.13.3.4 Usage at MSFC - Mission Support

After the launch of Skylab, inflight problems that required EVA activity were simulated on the NBT and alternate hardware concepts were evaluated. A final concept was selected and verified and crew procedures were developed as shown in Figure 2.13-16. These included:

- Twin pole concept for shading the OWS.
- Deployment of SAS wing #2.
- Installation of a rate gyro package.
- S193 antenna rotation.

2.13.3.5 Conclusion

The following considerations should be given to future design of neutral buoyancy trainers:

- Solid aluminum skins are preferred over expanded metal in that they are more durable, facilitate replacement of equipment, and provide more realistic closure for the crew.
- Kickout panels should be used for emergency egress.
- Functional hardware should be configured for on-site repair.
- All trainer modules should be electrically bonded together to prevent corrosion from "battery action".
- Zinc or magnesium sacrificial anodes are of no use for aluminum protection.
- Type 2024 aluminum (6061 for welded parts) is a preferred metal.
- Type 17-PH Stainless Steel is a preferred spring material.

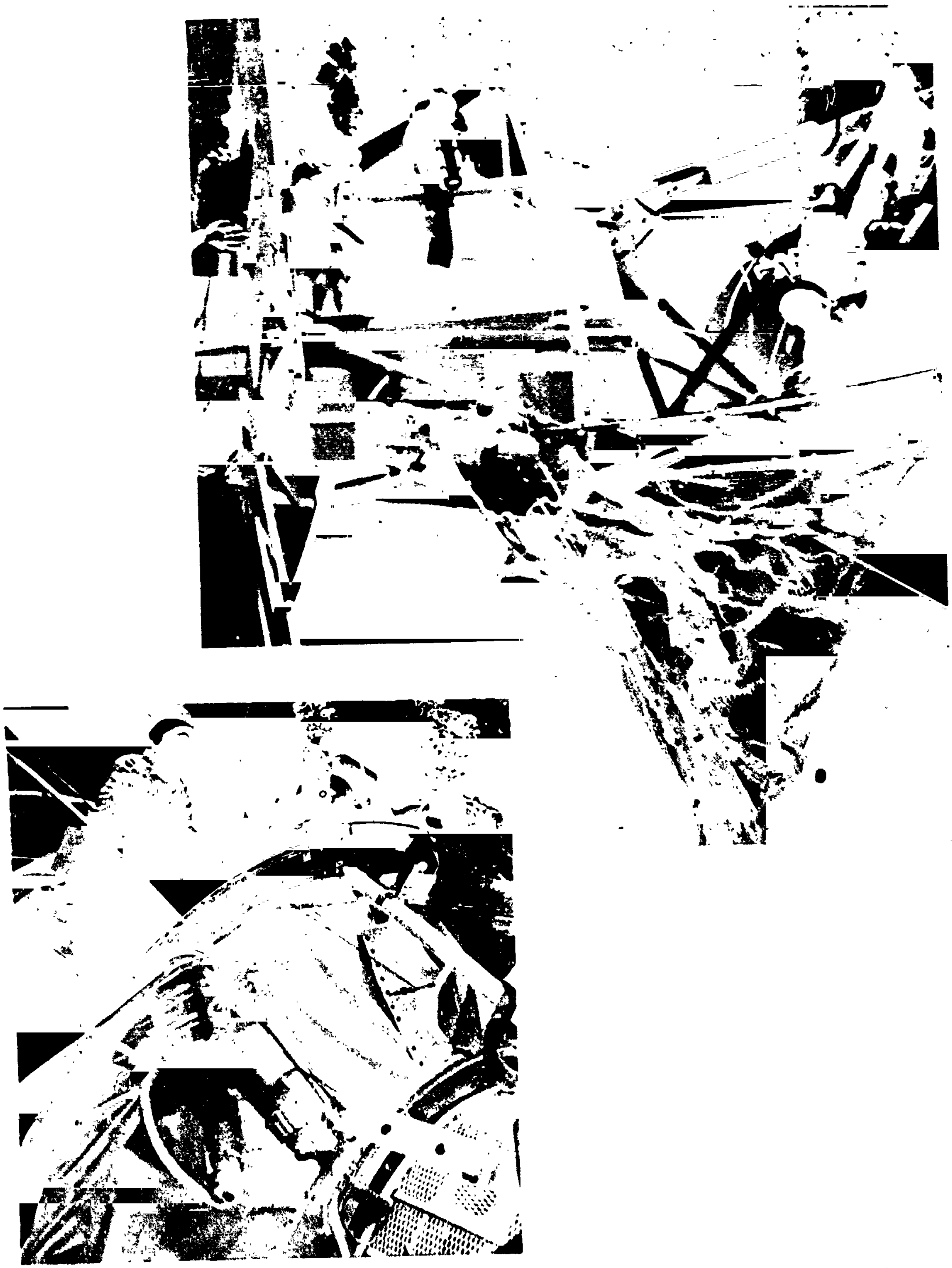


FIGURE 2.13-16 NEUTRAL BUOYANCY TRAINER – MISSION SUPPORT ACTIVITY

- Riveted or bolted assemblies are easier to maintain than welded assemblies.
- Hoisting lug locations should be compatible with procedures for in-tank assembly.
- Tapered guide pins are preferred for mating modules underwater.
- Aluminum alloy sheet, bar or rivets which have a high-magnesium content should be avoided as they tend to disintegrate underwater.
- Avoid "closed cell" design of locking devices, connectors, or any functional equipment to preclude "water lock" during underwater operations.
- Functional Lights should be of flight configuration, but designed for underwater usage.
- Rubber base paint and primer should be used on all surfaces.
- Thermal curtains and beta bags should be fabricated from water-compatible material, such as vinyl laminated Facilon.
- All hidden surfaces of aluminum parts (inside tubes, handrails, closed areas, etc.) should be alodined to retard aluminum hydroxide formation.

2.13.4 Skylab Systems Integration Equipment (SSIE)

In accordance with CCP 214, MDAC-E was requested to support NASA in the fabrication and installation of equipment on the Structural Test Article (STA-3) structure to produce the SSIE Trainer. The SSIE included simulated equipment for the STS, tunnel section and external EVA area, including the FAS and DA.

Engineering support included marking up drawings for equipment within the Airlock Module and for external equipment within the EVA area. These marked up drawings consisted of "second originals" of either trainer drawings or flight hardware drawings. Where these drawings were not suitable, new drawings were made. All drawings were forwarded to NASA directly and were not released formally through the MDAC drawing release system.

All available hardware from either spare parts or parts that were rejected as not "flightworthy", but which could be used as non-functional parts, were forwarded to NASA for installation on SSIE. These parts were

identified as available parts on drawings where they were applicable. The fidelity of parts that were to be fabricated was also listed on each drawing. Parts that were available (i.e. trainer parts or non-functional production parts) were reidentified with a "61X" prefix before shipment to NASA. A list was provided to MSFC indicating all ballast to be removed from the STA-3 before installation of hardware.

MDAC-E provided liaison engineering services at MSFC to support the fabrication of parts to be installed on SSIE. All parts that were not available were fabricated at MSFC (with the exception of internal and external lights, modification of EVA hatch, Pressure Equalization Valves for Internal hatches, two (2) EVA clothesline assemblies and stowage boxes and one (1) Fire Sensor and modified Control Panel, all of which were furnished by MDAC-E).

Installation drawings were furnished for mole sieve covers and stowage boxes. Marked up redline prints were supplied for wiring installations for functional equipment. All other equipment installations were accomplished by using available installation drawings of either the NASA Trainer or flight hardware assemblies.

After completion of SSIE, it was used for crew evaluation, press conferences and mission support.

2.14 EXPERIMENTS

During the design, manufacture, test and orbital operations of the Skylab vehicle, the Airlock provided support to the Skylab experiments. Electrical power was provided to the experiments and the experiment data was recorded and transmitted to ground stations. MDAC-E was responsible for installing four experiments outside the Airlock Module and for designing and installing an M509 Recharge Station inside the Airlock Module. Because all experiment hardware was Government Furnished Equipment (GFE), MDAC-E was responsible only for mounting brackets, support hardware, electrical cables, crew interface, and the installation and total system tests with the integrated experiments. The four external experiments and the nitrogen recharge station were successfully operated during all three manned Skylab flights. There were no anomalies during the flight for the experiment support equipment or the nitrogen recharge station. Flight results indicate that the crew interface experiments were easily accessible to the flight crew. Experiment locations are shown in Figures 2.14-1.

2.14.1 M509 Nitrogen Recharge Station

The function of the M509 Recharge Station was to recharge high pressure nitrogen bottles for M509 and T020 experiment operations. The high pressure gaseous nitrogen was used as a propellant for untethered flying of the astronaut maneuvering equipment (AME) in the orbital workshop.

2.14.1.1 Design Requirements

The Airlock Module provided a 3000 psi nitrogen recharge station to pressurize the 1500 cu. in. M509/T020 bottles. Requirements were to design a recharge stowage rack in the aft airlock compartment and modify the aft instrument panel to incorporate the required hand valves, metal flex hose, and GFE quick disconnect couplers. Pressure from the AM supply system to the recharge bottle was between 3107 psia and 300 psia at a temperature of 100°F or equivalent pressure and temperature resulting in the same gas density. For safety purposes, the maximum flow rate could not exceed 5.7 lbs per min. The design criteria to maintain 1500 psia supply pressure after 50 recharge operations required special manifolding, valving, and fill procedures. Physical interface requirements for the M509 experiments were defined in ICD 13M07406A.

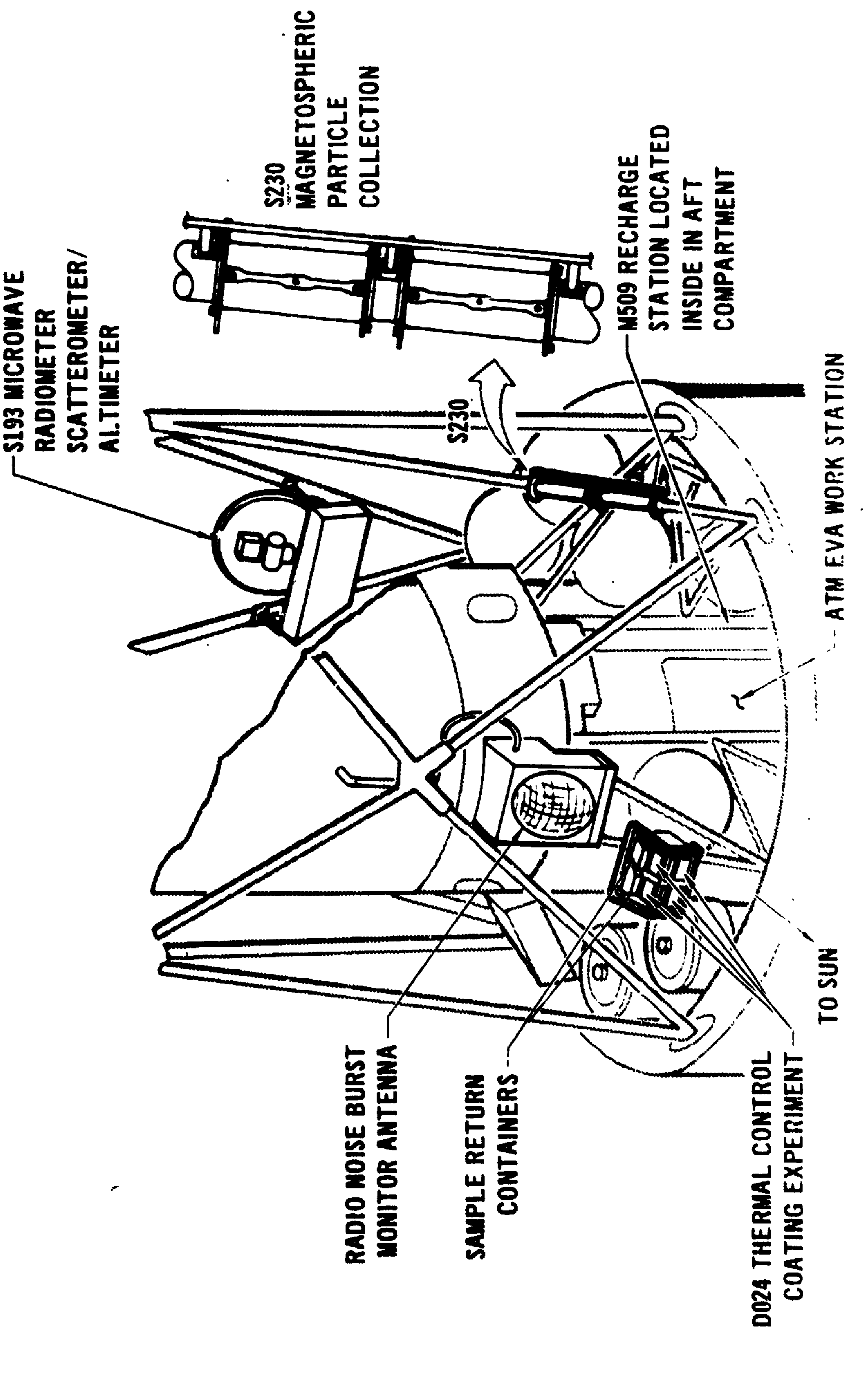


FIGURE 2.14-1 EXPERIMENT LOCATIONS

2.14.1.2 System Description

The M509 recharge station was comprised of a stowable rack for M509 bottle retention during fill and a control panel which provided supply valves, vent valves and a flex hose to deliver high pressure nitrogen. Figure 2.14-2 is a photograph of the M509 recharge station in the Airlock Module aft compartment, showing the M509 bottle mounted in the recharge station rack; the bottle is approximately 14 inches in diameter including outer cover.

In use, the rack was erected, the M509 bottle clamped in place and the flex hose QD attached to the M509 bottle fill port. Control valves on M509 Recharge Station provided isolation capability for two of the six Airlock nitrogen supply tanks for bottle top-off. After filling, the flex hose was vented, decoupled, and stowed. The M509 bottle was then removed from the rack and the rack stowed. Rack stowage capability allowed easy crew passage through the aft compartment.

The valves and manifolds shown on M509 Recharge Station (Figure 2.14-2) allowed choice of Airlock nitrogen supply tanks for M509 refill such that a high pressure nitrogen supply was available through the entire Skylab mission. Initial fills were taken from the four ECS nitrogen supply tanks with bottle top-off supplied by the two isolated tanks.

2.14.1.3 Testing

M509 system functional tests were conducted at both MDAC-E (St. Louis) during Simulated Flight and KSC. St. Louis tests used a GSE 3000 psi nitrogen source. Fit checks at MDAC-E prior to functional tests resulted in redesign of the fill hose routing and length to eliminate side loads induced at the QD interface. The stowage nipple for the fill hose was also relocated. Leak checks and flow checks without the M509 bottle at St. Louis validated flow limiting orifice size. During St. Louis function testing, three M509 bottles were filled to 2950 psi and touch temperatures were monitored; the highest temperature recorded was 102°F measured at the metal boss at the fill end of the tank. Fill tests assured that bottle growth due to temperature and pressure increase would not cause binding or fit problems in the rack assembly. A vent test identified the requirement for a vent hole in the M509 Recharge Station. KSC tests revalidated the leak and fill checks using the Airlock nitrogen supply tanks.

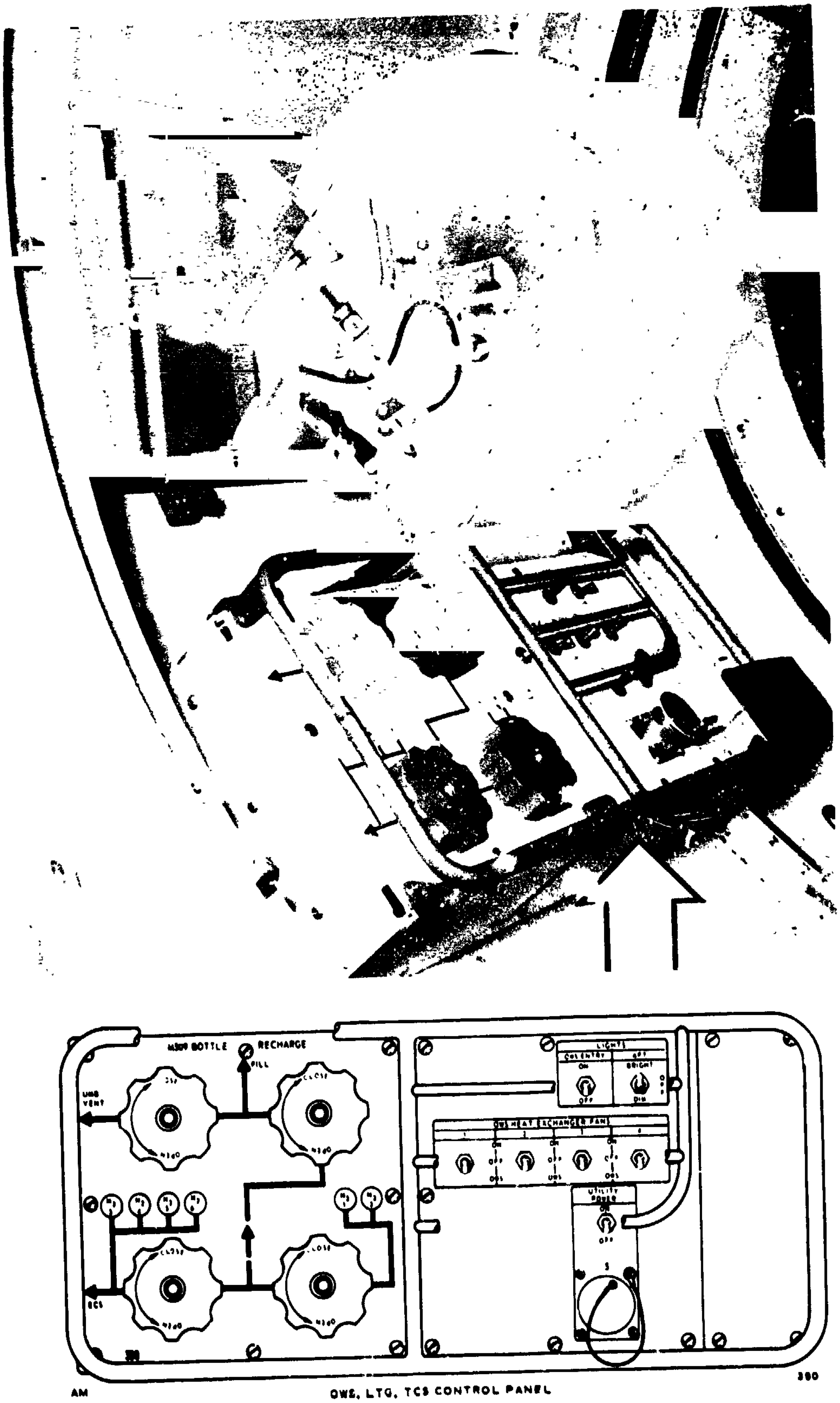


FIGURE 2.14-2 M509 RECHARGE STATION AND HOLD-DOWN BRACKET

2.14.1.4 Mission Results

No system anomalies were noted in recharge station operation during all fill cycles performed during the three manned missions. The manifold and valving procedure used for controlling nitrogen supply was effective as shown by the 1850 psi top-off pressure available at the end of SL-4 mission. Low cluster cabin gas leak rates required preconditioning of cabin atmosphere to accommodate the nitrogen added by unsuited M509 and T020 flights and the oxygen added by suited flights. Pre-experiment atmospheric venting and oxygen enrichment countered the nitrogen added by the unsuited flights. Total cabin gas pressure increases were less than 1 psi as predicted.

2.14.2 S193 Experiment

Experiment S193, Microwave Radiometer/Scatterometer/Altimeter, investigated the usefulness of active and passive microwave systems to study the earth from orbital altitudes. The epxeriment was composed of three sensor systems. The radiometer/scatterometer sensors studies the interrelationships between radar return and microwave thermal emission. The altimeter measured spacecraft altitude and surface scattering characteristics for very short duration pulses, and investigated several instrument parameters for use in the optimization of future operational radio frequency (RF) altimeters.

2.14.2.1 Design Requirements

The Airlock Module provided structural mounting attachments on the deployment assembly struts for S193 installation. Requirements of the installation included:

- Attachment structure weight not to exceed 15 pounds.
- Positioning of the antenna to beam scan in the YZ and XZ planes without protrusion of external structure into the antenna beam at specified data taking angles.
- Mechanical mounting tolerance of $\pm$ 0.5° to all axes.

All physical interface requirements were defined in ICD 13M07398.

2.14.2.2 System Description

The S193 consisted of an antenna and electronics package which was mounted directly on the ATM deployment trusses with 16 bolts (Figure 2.14-3). The antenna transmitted energy and received the reflected energy during the active scatterometer and altimeter operating modes, and received earth-emitted energy during the passive radiometer mode.

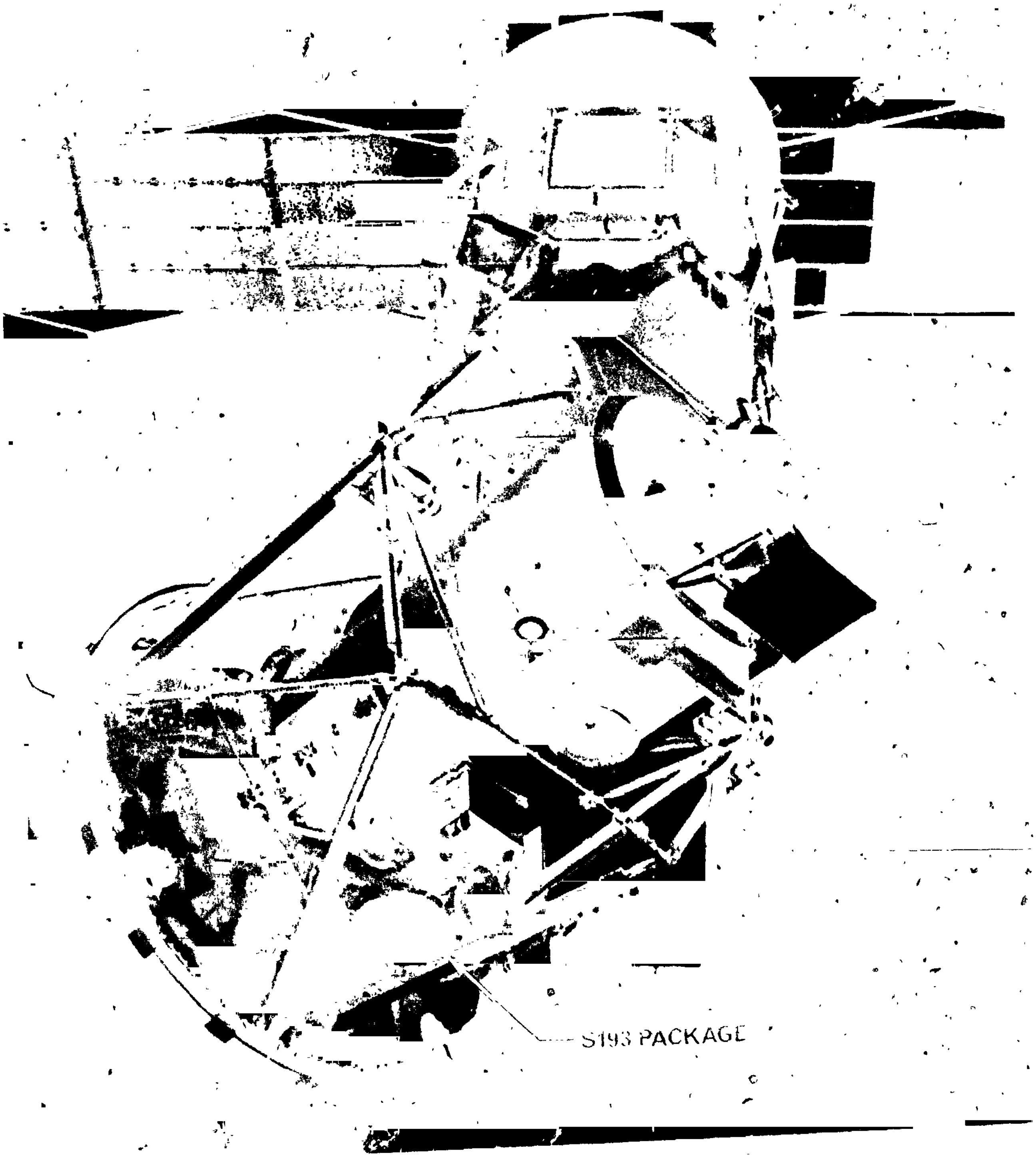


FIGURE 2.14-3 S193 PACKAGE INSTALLATION

2.14.2.3 Testing

Fit verification and functional testing was included in AM systems test. The JSC vibro-acoustic test vehicle included a simulated S193 installation.

2.14.2.4 Mission Results

Airlock structural mounting provisions for the S193 experiment package adequately satisfied all design requirements. In addition, the Airlock design philosophy of eliminating all external sharp edges throughout the spacecraft allowed an EVA repair on S193 without concern for suit damage because of working in an area not designated for planned EVA.

2.14.3 D024 Experiment

The purpose of D024 experiment was to determine the effects of space radiation on selected experimental thermal control coatings and polymeric samples.

2.14.3.1 Design Requirements

The Airlock was required to provide a smooth, quick-release type mounting attachment located in view of the sun for two thermal control coating trays, two polymeric film strip trays and two sample return containers. The D024 module was designed for pressure suited retrieval of the experiment trays and containers. D024 interface requirements were defined in ICD 13M12024A.

2.14.3.2 System Description

The D024 module was installed in the EVA quadrant on Airlock truss #4, positioned to be clear of EVA film recovery paths. Each experiment tray was attached to the module with four snap fasteners per tray and one tethered quick release pin. Two sample return containers fit into cutouts in the D024 module. Stainless steel plates with bonded rubber pads were installed in the cutouts to provide a snug fit for the return containers. One tethered quick release pin was used to hold each container in the module. A guard rail was provided around the periphery of the module to provide one-hand retrieval of the experiment trays and containers. A white running light was relocated to the D024 module and wired to the EVA lighting switches for experiment lighting. Figure 2.14-4 illustrates the D024 installation.

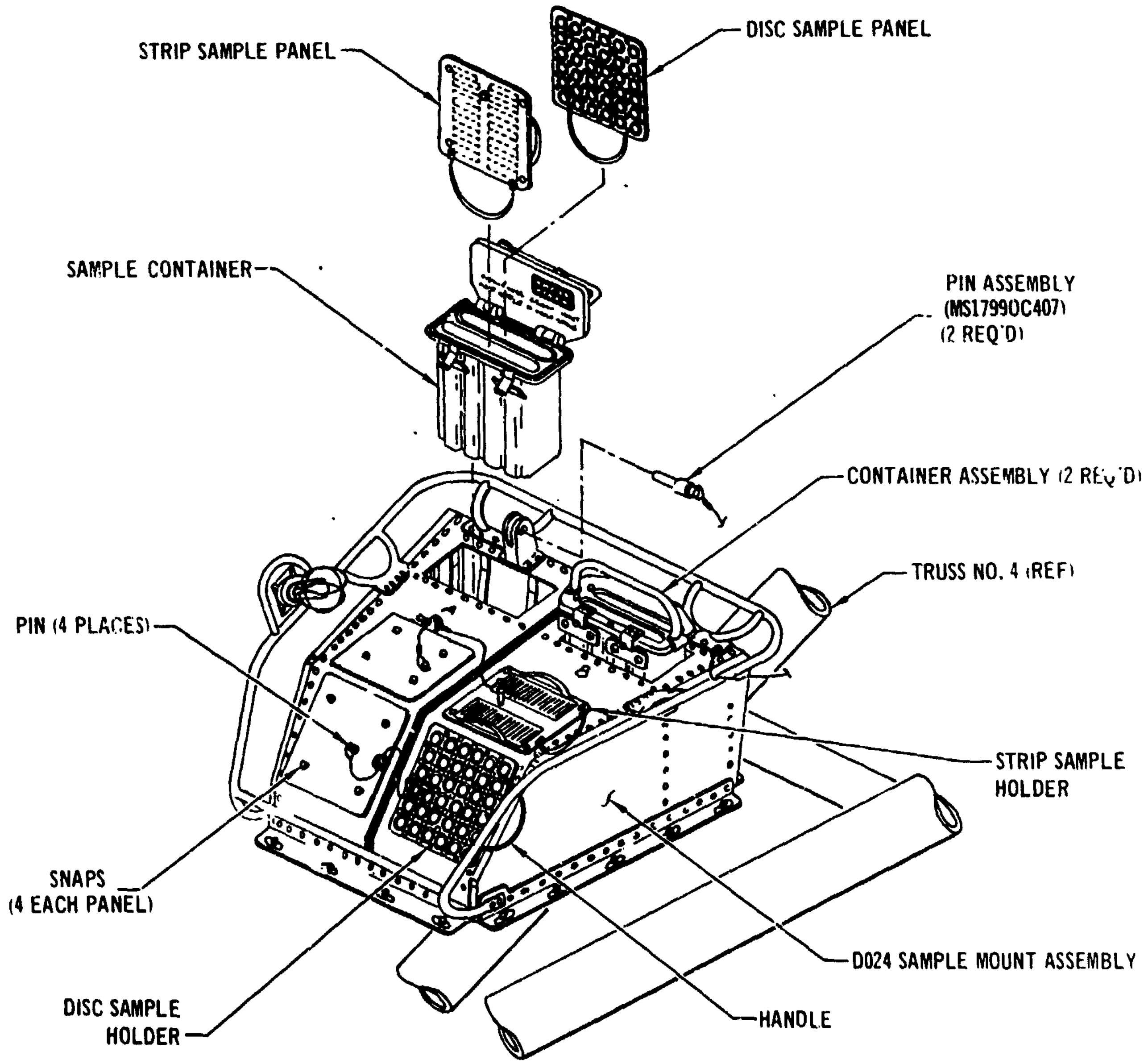


FIGURE 2.14-4 D024 THERMAL CONTROL COATINGS

2.14.3.3 Testing

Functional testing was successfully accomplished in the Neutral Buoyancy and One-G trainers. Fit check verification was conducted during AM systems testing. No structural testing was conducted on the module installation as operation structural loads on this low mass were less than ground handling design loads.

2.14.3.4 Mission Results

The D024 experiment module structural mounting proved adequate and satisfied all design requirements. EVA retrieval of the experiment trays and containers were satisfactorily performed. The SL-2 crew thought that foot restraints for D024 experiment would have made it easier for tray retrieval but the SL-3 crew stated that the hand hold restraints were just right for the D024 task to be performed. The SL-4 crew used the D024 module to attach samples of the MSFC twin pole sail material normal to the sun. The samples were successfully retrieved on the last SL-4 EVA.

2.14.4 S230 Experiment

The purpose of the Magnetospheric Particle Compsition Experiment (S230) was to measure fluxes and composition of precipitating magnetospheric ions and trapped particles through the use of a foil collection technique. Aluminum and platinum foils were mounted on the Skylab spacecraft for particle collection in the radiation environment. The foils were then returned to earth and the implanted gases analyzed by means of an UHV mass spectrometer.

2.14.4.1 Design Requirements

The requirement to install the S230 experiment was made so late in the program that there was no ICD defining the mounting interface. The experiment required installation of two hard mounted spools (containing foil collectors) located near mobility aids to allow for pressure suited retrieval. An earlier design decision to not remove handrail D2 after D021 was cancelled made it possible to accommodate the installation of this experiment at KSC three days before launch.

2.14.4.2 System Description

Two S230 spools each containing two foil collectors were installed in the EVA quadrant on a DA strut under handrail D2. The spool halves were bolted together, saddle fashion on a DA strut. (See Figure 2.14-5.)

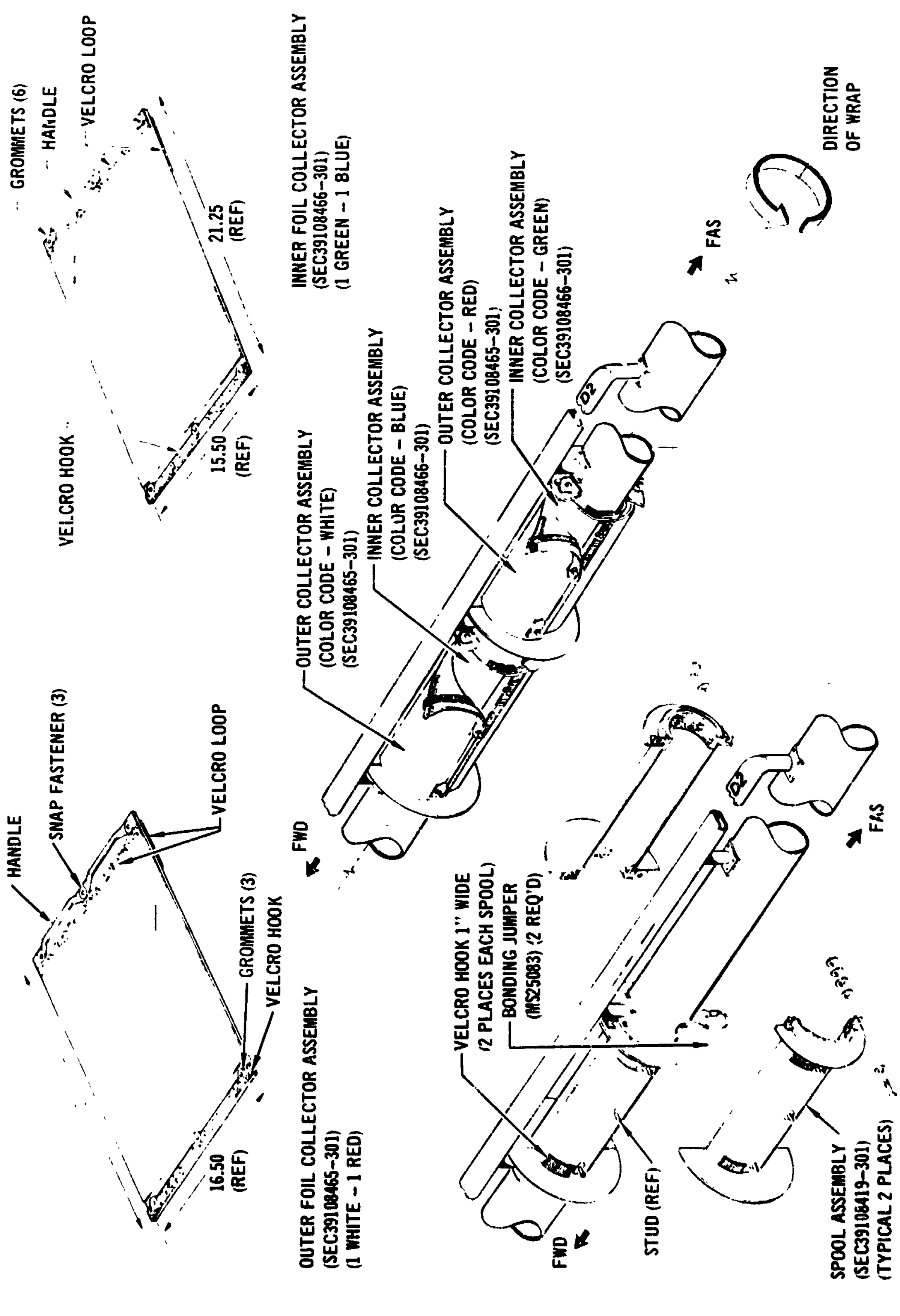


FIGURE 2.14-5 S230 EXPERIMENT

2.14.4.3 Testing

Flight crew EVA procedures were evaluated in the neutral buoyancy trainer at MSFC. There were no fit checks prior to the installation of the flight spools and collectors at KSC. Since there were no test articles, installation verification was accomplished by inspection of the installed flight hardware to assure the equipment met the basic design requirement of cluster requirements specification (RS003M00003).

2.14.4.4 Mission Results

The S230 experiment was satisfactorily performed and the astronauts were able to retrieve the foil collectors without mishap.

2.14.5 Radio Noise Burst Monitor

Function of the Radio Noise Burst Monitor (RNBM) was to monitor solar activity and provide an aural and visual indication of the onset of a microwave energy burst from the sun, indicative of high solar flare activity, thus allowing manual activation of other solar flare experiments.

2.14.5.1 Design Requirements

The Airlock Module provided structural mounting provisions for the RNBM external elements through four mounting pads attached to the antenna package. Requirements of the installation were to position the electromagnetic centerline of the RNBM antenna to within ±1° of the cluster Z axis, to withstand launch stresses and the orbital environment, and to enable the antenna to have a unobstructed view of the sun while in solar inertial attitude (See Figure 2.16-1). The RNBM was positioned to be clear of EVA film recovery paths with its beam directed between the arms of the ATM solar array.

2.14.5.2 System Description

The RNBM consisted of a microwave receiver, an antenna assembly, and an interconnecting cable assembly. The antenna and its cable assembly were mounted external to the Structural Transition Section (STS) with no pressure wall penetrations.

The antenna, a 24" parabolic reflector, included a microwave horn and its waveguide feed elements. Four mounting pads on the rear of the reflector provided the structural interface to the Airlock Module.

2.14.5.3 Testing

System verification of the RNBM was performed at MDAC-E during simulated flight and Altitude Chamber testing. Acoustic vibration tests performed on the Structural Test Article (STA-3) verified the integrity of the Airlock Module interface design.

2.14.5.4 Mission Results

Airlock Module structural mounting provisions for the RNBM antenna satisfied all design requirements during all mission phases. Functional performance of the RNBM was satisfactory.

2.14.6 Conclusions and Recommendations

The Airlock Module experiment interfaces proved more than adequate to meet all design requirements. The experiment installations successfully withstood the launch stresses and the orbital environment. all crew operations were performed successfully. An earlier design decision not to remove handrails after cancelation of experiment D021 made it possible to accommodate the addition of S230 experiment late in the program. Design foresight in control and elimination of sharp edges outside the planned EVA areas paid off during S193 EVA repair activity and should be considered in future programs.

It was necessary to move the M509 bottles from the OWS storage rack to the recharge station in the Airlock Module for refill. In future programs, it would be convenient to have recharge capabilities at storage racks to eliminate moving bottles. Because Airlock size prevented bottle storage in the AM and because it would have been necessary to route high pressure lines across the AM/OWS interface to provide N_2 at the stowage rack, the as flown location of the M509 recharge station was an acceptable compromise.

Crew station integration was successful on Airlock Module for related experiments. Future programs should continue emphasis on early integration of all crew interfaces with experiment hardware, to develop commonality of handles, control and displays and to insure adequate accessibility.

2.15 GROUND SUPPORT EQUIPMENT (GSE)

This section describes all categories of GSE required in support of the AM, FAS, and DA flight articles. Payload Shroud (PS) peculiar GSE is described in MDC Report Number G4679A, "Skylab Payload Shroud Final Technical Report". Specific references to the PS GSE or activities are included herein to provide continuity with and cross-correlation between this report and G4679A.

A. Task Summary - A total of 556 different major GSE end items were required to support the AM, FAS, DA, and PS during test, checkout, handling, servicing and launch operations. A summary of GSE by classification is as follows:

- Two hundred forty items were supplied as GFE from other programs, primarily from the Mercury, NASA Gemini, Gemini B, and S-IVB programs, and modified as required to satisfy Skylab requirements. This GFE, after required modification, represented roughly 30% of the value of the Airlock GSE.
- Thirty-three items were Payload Shroud GSE, provided by MDAC-W.
- One hundred ten items were classified as ancillary equipment items, as explained in Paragraph 2.15.1.
- One hundred ninety items were new designs by MDAC-E.

B. General Description - GSE is the nonflight hardware and software used in support of the flight article to satisfy a specific support or test function. Although GSE is not generally considered to be mission support equipment, such as tracking and in-flight data reduction equipment, a large GSE complement was used to support the Skylab Unit 2 flight article, which was used extensively in support of the U-1 mission.

C. GSE Usage - Airlock GSE was used to inspect, test, adjust, calibrate, appraise, gauge, measure, repair, assemble, disassemble, handle, transport, safeguard, protect, store, record, actuate, service, checkout or to otherwise perform a designated function in support of the flight article during development testing, manufacturing assembly, acceptance testing, systems testing, delivery to KSC, prelaunch checkout, and launch.

D. Program Philosophy - MDAC-E GSE Engineering designed new GSE and/or modified existing GFE as required to satisfy Airlock Module (AM) and Payload Shroud (PS) support requirements to provide the lowest cost complement of GSE, considering the following:

- Overall mission requirements.
- Interrelationship of individual GSE items.
- Vehicle subsystems analyses.
- Vehicle mission.
- GSE support areas.
- Test operations.
- Launch operations.
- Facility requirements.
- Effect on program costs.
- Maintainability.
- Reliability.
- Human engineering.
- Safety.

E. Overall GSE Performance - The GSE performed its intended functions during all phases of program operation. Problems were experienced in the following areas, but were resolved without imposing program delays.

(1) Acceptance & Certification Tests - Some of the newly designed fluid and electrical operational GSE experienced initial set-up and calibration problems. These discrepancies were resolved prior to NASA acceptance of the item. All mechanical GSE items passed proof load certification tests.

(2) Trial Installation and Fit Checks - Minor discrepancies and problems occurred during the trial fit/installation checks of several mechanical items, most notably on the internal work platforms used inside the PS. These fit checks, conducted both at the contractors Huntington Beach facility and at JSC, were scheduled such that the appropriate design changes were easily incorporated without prelaunch activity impact.

(3) GFE Operational Maintenance - Several of the more complex fluids GSE units, such as high pressure test benches, LN_2 to GN_2 converters, etc., experienced continual maintenance problems, due to the demands

of extended usage and useful life. A rigorous in-house maintenance program prevented downtime from creating any serious problem.

(4) GSE Shipped to KSC - GSE used at KSC performed as required, although problems were experienced on the following units:

(a) Solar Array Wing Simulator (SAWS) - Electrical component malfunction and other downtime on the SAWS unit created some slippage in the SAWS test schedule, but major impacts were avoided by shipping and substituting spare parts from a St. Louis based unit.

(b) 52E180172 Refrigeration Unit - This unit developed slow leaks in a Freon loaded cooling loop which, while not serious enough to delay test or launch schedules, was a source of concern. Corrective action was limited to frequent recharges of the Freon system, since the unit was installed on the mobile launcher where major repair activity was not feasible.

(c) 52E180004 Ground Cooling Unit - Several minor, but annoying, instrumentation problems were encountered on the unit, which had temperature and pressure remote monitor capability built into the refrigeration portion of the unit's system.

The temperature sensing problem was ultimately determined to be a thermocouple grounding isolation problem, wherein the ACE system, which monitored the thermocouple, was at a different ground potential than the cooling unit.

The pressure sensing problem was traced to a pressure transducer, physically located in a pumping unit on the 52E180004 unit, which was contaminated by the corrosive environment of the pump. Sealing the transducer against this environment resulted in satisfactory corrective action.

(d) 52E180032 O_2/N_2 Gas Servicing Panel - A large amount of contamination was introduced into the internal components of this unit during test and checkout of the AM/MDA O_2/N_2 Gas Servicing System. Intensive investigation failed to reveal the source of this contamination. The affected unit was dismantled, cleaned, and reconditioned. The contamination problem did not recur.

(e) 61E010727 AM/MDA Inverted Docking Kit - A mechanical linkage adjustment problem was encountered during the AM/MDA inverted docking test with the Apollo Command Module. The linkage problem was resolved by field personnel utilizing standard adapters. The test was accomplished on schedule.

2.15.1 GSE Categories and Classifications

The Ground Support Equipment used in support of the Airlock Module (AM), Fixed Airlock Shroud (FAS), Deployment Assembly (DA), and Payload Shroud (PS) was categorized as follows:

- Handling, transportation, and mechanical GSE.
- Electrical/electronic GSE.
- Servicing and fluids GSE.

The total complement of GSE end items was documented and defined in MDAC-E Drawing No. 61E000001, "Airlock Ground Support Equipment Index", which provided a functional description of each prime end item, identified each unit by serial number, stated quantity requirements for items at each using location, and identified shared or sequential usage of the same item. GSE end items were further classified as either "prime" or "ancillary" equipment, as follows:

A. Prime Equipment was that equipment which satisfied a scheduled flight module support function(s) and for which MDAC-E had design responsibility.

B. Ancillary Equipment was that which satisfied any of the following criteria:

- Factory test equipment, which satisfied contractor facility unique test requirements.
- Test equipment used to support development tests and fault isolation and which was not required for system performance verification.
- "Off-the-shelf" commercially available equipment, usable without modification or reidentification.
- Equipment for which an associate contractor had the design responsibility.

The above classifications were further subdivided in the Index by specific GSE functional categories such as ECS GSE, Communications GSE, etc.

A special section was provided in the Index as a convenience for the segregation of GFE items. GFE was existing equipment from prior programs which had a utility application as either prime or ancillary equipment on the Airlock Program.

2.15.2 GSE Development and Design Requirements

2.15.2.1 GSE Development Concepts

MDAC-E developed the GSE complement required to accomplish the various Airlock operational support and test functions from factory to launch through optimum use of the following hardware, facilities, and documentation.

- Existing Gemini and S-IV Stage GFE, with minimum modification, selected on the basis of utility and availability.
- Other GSE supplied as GFE on a loan basis by NASA or subcontractors.
- Existing factory facilities as required to support the Airlock Module and GSE related support activities.
- Existing facilities at KSC to support the AM and GSE related operations.
- New Airlock Module GSE, including ancillary equipment.
- Interface Control Documents (ICD's) and other program documentation to establish and maintain compatibility between GSE and the facilities and interfacing equipment other than Airlock.

This concept resulted in the minimum amount of new, AM-peculiar GSE.

2.15.2.2 Development Plan

The concepts summarized above were definitized in MDC Report G241, "Airlock Ground Support Equipment Plan," revised 4 October 1971, which detailed the contractor's basic plan for the development of the Ground Support Equipment (GSE) necessary to support the AM/FAS/DA/MDA during assembly, test and prelaunch operations. This plan defined GSE activities from initial design through customer acceptance.

2.15.2.3 GSE Requirements Implementation

The specific requirement for each end item or system was generated by the need to perform a given operation or accomplish a specific test. The efficient conversion of a functional requirement to operational hardware was the responsibility of MDAC-E GSE Engineering.

The key to the effectiveness of the MDAC-E GSE Engineering function lay in the assignment of specific engineers with overall responsibility for each GSE end item. Thus, each end item normally had a designated GSE Systems Engineer assigned to it

who had the authority and responsibility for assuring that the item fully met its function, without danger to personnel or damage to equipment, airborne or ground. The GSE Systems Engineer performed necessary analyses and acted as the focal point for all coordination activities associated with the design of the hardware. Implementation of the identified requirements was the function of the responsible GSE Design Engineer, who was the point of contact with Manufacturing departments responsible for producing hardware meeting design specifications.

2.15.2.4 General Design Requirements

Specific, program-imposed GSE design requirements were limited to mandatory compliance with MDC Report E946, "Airlock Performance and Configuration Specification," and MDC Report G671, "Airlock Safety Plan." In addition, the AM-peculiar GSE conformed to the applicable Design and Procedural Standards listed in Appendix A, Attachment I of the AM Statement of Work (SOW). Residual GSE from other programs, was only required to comply with the specifications and standards in effect on the program for which the GSE was originally developed. This was in accordance with Appendix A, Paragraph 1.1, of the AM SOW.

Where specific program contractual or procedural requirements were not imposed on the design of the GSE, MDAC-E in-house design standards and practices governed.

Functional requirements were imposed on the design of GSE end items and systems by the AM vehicle/system configuration, AM vehicle tests required during buildup and final assembly, environments in which the GSE was to be used, and other factors related to the definition and utilization of GSE with flight hardware in a specific manner within selected facilities. These functional requirements were documented by GSE Systems Engineers and reviewed with the NASA at informal working group meetings and Preliminary Design Reviews.

2.15.2.5 GSE Design Criteria

A. Mechanical GSE Design Criteria - Figure 2.15-1 indicates the load factors and criteria utilized in the design of AM and PS handling and transportation GSE. The source of these factors is also shown.

DESIGN STRESSES SHALL BE THE YIELD STRESS OR THE ULTIMATE IF NO YIELD STRESS IS GIVEN. YIELD OR ULTIMATE STESS VALUES FOR THE MATERIAL AND TYPE STRESS INVOLVED ARE IN ACCORDANCE WITH MIL-HDBK-5B.

DESIGN LOADS SHALL BE BASED UPON THE STATIC WEIGHT OF THE ITEM (PLUS SUPPORTING EQUIPMENT) MULTIPLIED BY THE LOAD FACTOR AND THE SAFETY FACTOR.

HANDLING MODE	LOAD FACTOR/DIRECTION	SOURCE
1. AIR TRANSPORT EMERGENCY LANDING. (ALL FACTORS BASED ON ULTIMATE STRENGTH OF THE MATERIAL). ①	8.0G FORWARD ② 1.5G AFT 4.5G DOWN 2.5G UP 1.5G LATERAL	MIL-A-8421, REVISION "D", DATED 15 NOVEMBER 1972.
2. AIR TRANSPORT NORMAL FLIGHT AND TAXING. ①	3.0G FORWARD OR AFT ③ 3.0G DOWN OR UP 1.5G LATERAL	
3. GROUND HANDLING TRANSPORATION AT 5 MPH. ①	3.0G FORWARD OR AFT ③ 3.0G DOWN 1.5G LATERAL	④
4. GENERAL GROUND HANDLING (SLINGS, ACCESS FRAMES, ETC.).	3.0G AS REQUIRED ③	

NOTES:

① DIRECTIONAL LOAD FACTORS WERE APPLIED SEPARATELY AND INDEPENDENTLY.

② PRIOR TO RECEIPT OF REVISION "D" TO MIL-A-8421 MDAC HAS DESIGNED TO AN EMERGENCY LANDING CONDITION OF 8.0G FORWARD FOR SHIPMENT IN MILITARY AIRCRAFT. REVISION "D" DID NOT SPECIFY A FACTOR FOR FORWARD EMERGENCY LANDING CONDITION.

③ THE FOLLOWING MINIMUM FACTORS OF SAFETY WERE APPLIED TO THE DESIGN LOAD FACTORS TO DETERMINE THE RESPECTIVE ULTIMATE OR YIELD LOADS: 1.0 F.S. ON YIELD, 1.33 F.S. ON ULTIMATE.

④ THESE GROUND HANDLING LOAD FACTORS WERE THE MDAC-E LOAD CRITERIA FOR GSE. MIL-S-8512, REVISION "B", DATED 8 JANUARY 1958 WITH AMENDMENT #1, DATED 4 FEBRUARY 1959 AND/OR MIL-S-5944, REVISION "A", DATED 27 DECEMBER 1957 WERE USED AS DESIGN CRITERIA GUIDES.

FIGURE 2.15-1 DESIGN CRITERIA FOR HANDLING EQUIPMENT

Other detail requirements specified by MDC Report G671, "Airlock Safety Plan," and MDC Report E0047, "Payload Shroud CEI Specification" (Part I) included the following:

(1) The design of GSE systems precluded a single point failure which could create an additional or cumulative failure.

(2) Fail-safe features were incorporated to prevent injury to personnel or damage to property.

(3) Tethers were provided for tools to prevent flight vehicle damage due to falling tools.

(4) Toe plates were provided on all work platform edges to prevent loose objects from falling.

(5) Grounding straps were attached to all mechanical equipment in hazardous areas.

(6) Lifting/rotational devices and hoisting slings were designed for specific operations, with the worst case condition governing design

(7) Sling designs were checked to ensure that cable pull-off angles did not exceed 45 degrees from vertical.

(8) Hoist hooks, swivel eyes, pins and shackles were fabricated from drop forged steel or wrought iron. Hook or pin attach points were of built-up steel plates.

(9) Wire rope assemblies utilized only swaged fittings or multiple cable clamps.

(10) Certified proof load placards, which included limit or working load data, were affixed to each sling, hoist, or handling device.

(11) Handling equipment design permitted visual inspection of all components, where possible.

(12) Over-the-road transporters were equipped with dual independent braking systems.

(13) Roll-on/roll-off transfer and handling systems were utilized to the maximum practical extent to minimize lifting or hoisting of flight vehicle stages.

B. Electrical/Electronic GSE Design Criteria - The basic design requirements imposed by MDAC-E GSE Engineering on electrical/electronic GSE were as follows:

(1) Electrical Power and Control Equipment (included all equipment supplying power to the AM).

- Used floating ground system to eliminate ground loops.
- Incorporated current limiting power supplies with circuit breakers to protect flight systems from over-current conditions.
- Used over-voltage protection circuitry on the power supplies such that procedural or hardware malfunctions would not damage the flight hardware.
- Used separate power supplies for operating GSE. Such power supplies were isolated from any units supplying power to the AM.
- Monitor points originating in the AM were protected by AM circuit breakers. There was no connection of any GSE power to these monitor points.
- Control functions originating in the GSE systems were protected by circuit breakers or fuses.
- Electrical GSE was designed to preclude damage to flight hardware from possible procedural errors.

(2) Instrumentation and Data Acquisition GSE

- Isolated all AM monitor points from any GSE power and grounds.
- Provided simulation of AM flight hardware sensor isolation and impedance.
- Used power supply outputs protected with fuses to simulate sensor inputs.
- Minimized instrumentation monitoring via hardwires. Sensitive instrumentation circuits were normally not compatible with hardwire monitoring. Monitoring the Instrumentation System Pulse Code Modulation (PCM) output was adequate to determine the operational status of the system under test.

(3) Communications, Command, and TV System GSE

- Designed communications GSE input monitoring circuits with built-in isolation protection for flight equipment test points lacking such protection.
- Designed communications GSE monitoring circuits for negligible loading of a flight equipment test point including the event of GSE monitoring circuit failure.

- Accomplished communications test point isolation by using resistors, capacitors, transformers, and diodes in combinations imposed by the specific test point to be monitored.
- Used voltage regulated GSE power supplies with "crowbar" protection to preclude damage to flight hardware in the event of power supply failure. In all cases but one, GSE power supplies were separate from flight equipment power supplies. The exception was the emergency intercom used in St. Louis in which a common battery source powered the intercom and the AM Audio System during an emergency. The AM power buses were separated from the audio power lines in this event.
- Provided capability to determine the effect of communications GSE failure on the flight equipment by observing the monitored telemetry parameters for the system under test.
- Minimized possible damage to flight equipment due to human error by tape programming the DCS GSE, and by the use of low power RF signal generating devices, built-in GSE safety devices and test procedural controls.

(4) Simulators

- Duplicated the flight hardware being simulated. This included loading, circuit protection and isolation.
- Maintained complete isolation between any power supplies located in the simulators for GSE functions and the flight circuits.
- Used circuit protection provided by the AM in order to duplicate flight circuits.
- Provided circuit protection in the simulators for all other circuits.

C. Fluids GSE Design Criteria - Basic design requirements on fluids GSE were as follows:

- Relief valves were located immediately downstream of pressure regulators and were sized for full flow of a failed regulator.
- All flexible hose assemblies with pressures above 50 psig were mechanically restrained in each application to preclude damage to vehicle and/or injury to personnel in the event of line rupture per the requirements of MDC Process Specification 21015, "Safety Requirements for Hydrostatic and Pneumatic Pressure Testing."

- GSE was cleaned to the same cleaning specification as the flight system with which it interfaced.
- Inlet/outlet filters were included in all GSE, as required, to preclude contamination of flight systems.
- All hazardous operations were identified in Test SEDR's and End Item Operation and Service Manuals.
- Pressurization and purge equipment items contained, when required, pressure switches and solenoid valves to automatically halt gas flow to the vehicle should an overpressure condition occur.
- All fluids GSE items were designed to withstand a proof pressure level two times the maximum working pressure and a burst pressure level four times the maximum working pressure.

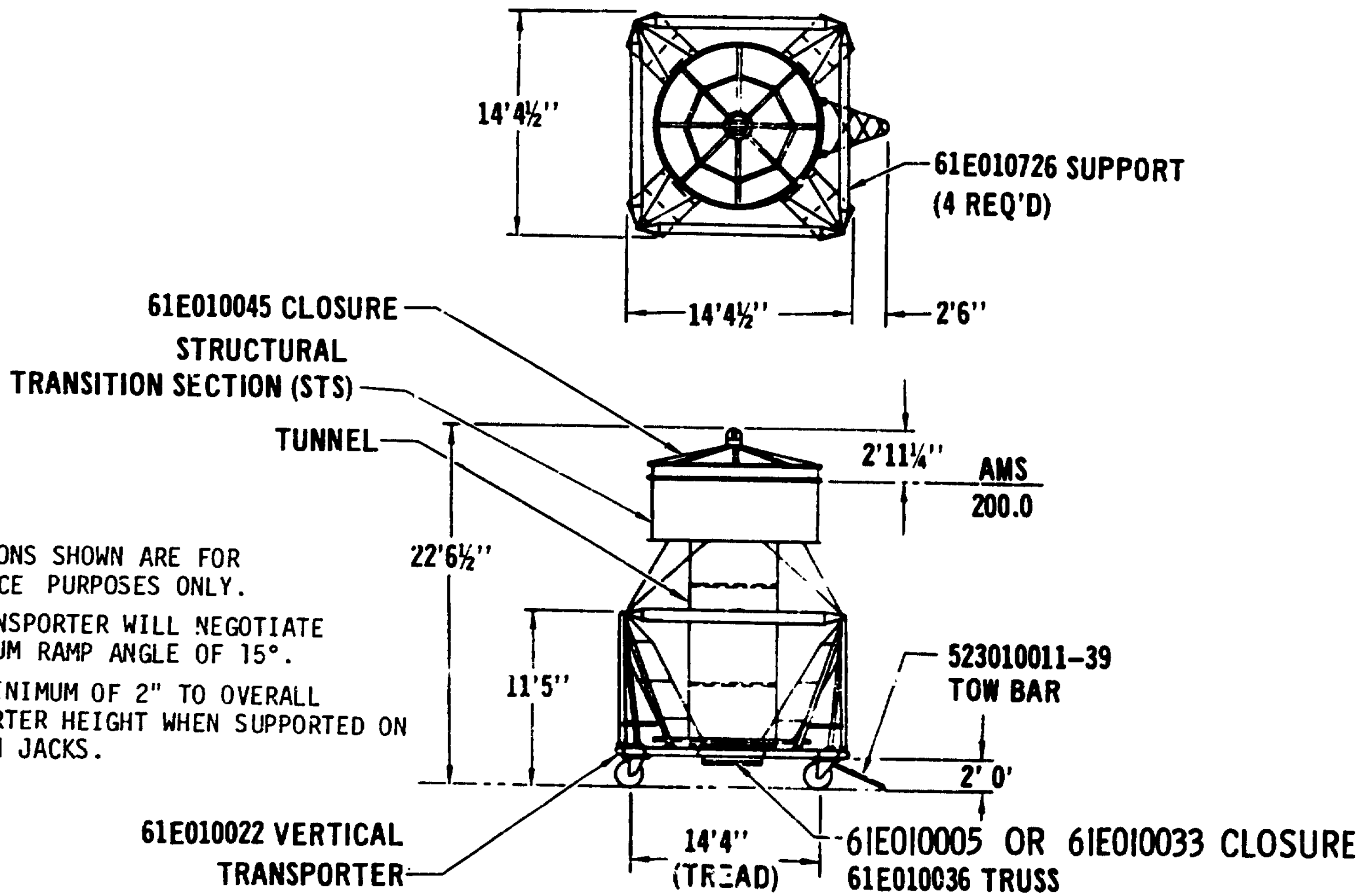
2.15.3 GSE Design Description

2.15.3.1 Handling, Transportation, and Mechanical GSE

This category of GSE provided the capability for supporting the AM at each defined work station or for accomplishing those operational functions such as transportation, lifting, rotation, insertion, mating, alignment, etc., as were required to fabricate, assemble and deliver these vehicle segments. Typical examples of this GSE include transporters, hoisting gear, support/access stands, fixtures, rotation devices, and air bearing pallets.

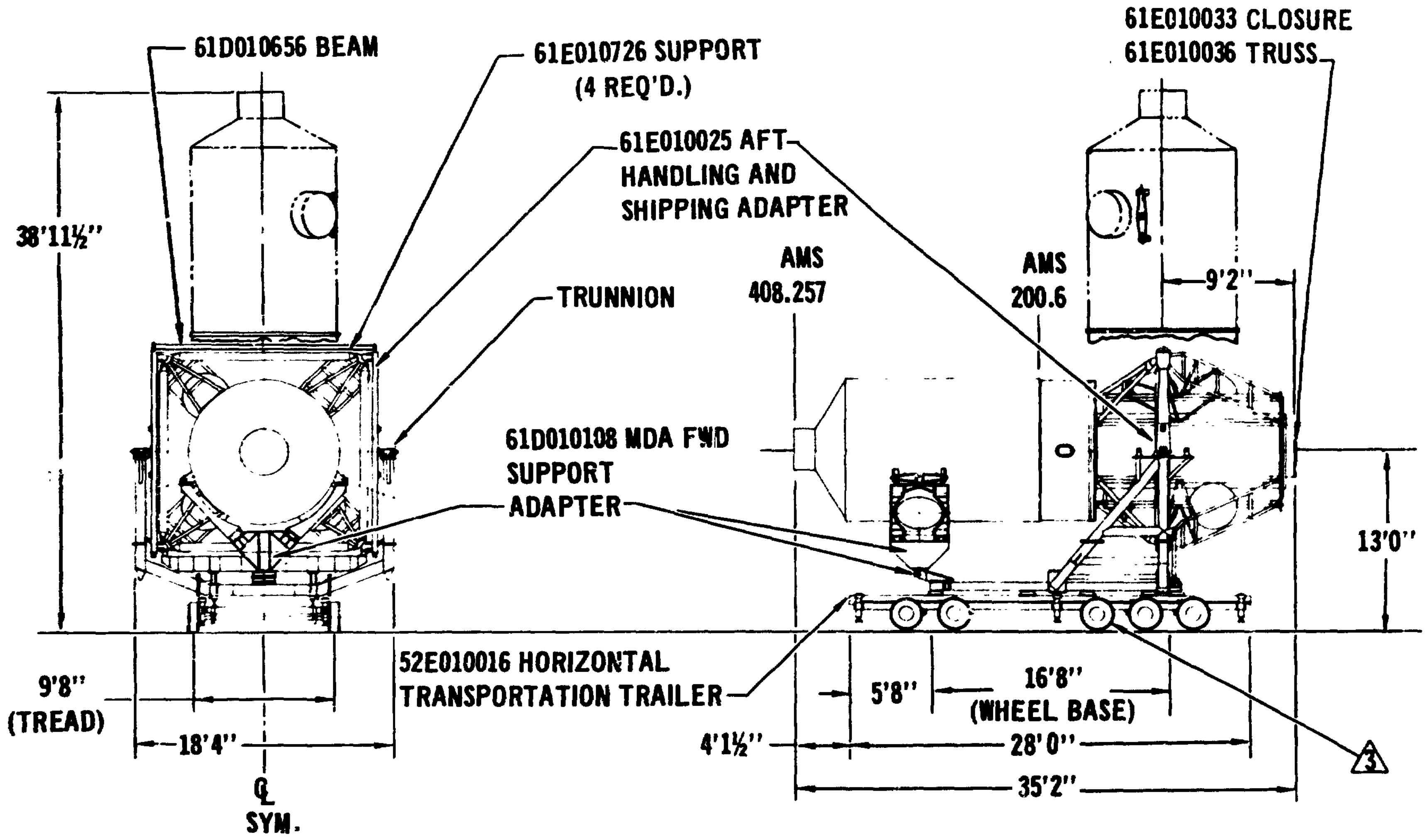
Mechanical, handling, and transportation GSE functional requirements for all AM and PS operations conducted from factory through vehicle mating operations at KSC were defined in MDAC-E Drawing SK041568, "Skylab Flight Units and Ground Support Equipment Flow Plan."

The preparation of this document required the integration of systems engineering data from all organizational elements to define the operations required in each assembly or test sequence. The approval of these requirements by NASA at various PDR's and CDR's formed the basis and justification for each mechanical GSE end item. Figures 2.15-2 through 2.15-5 illustrates these major flow plan end items.



NOTES:
1. DIMENSIONS SHOWN ARE FOR REFERENCE PURPOSES ONLY.
2. THE TRANSPORTER WILL NEGOTIATE A MAXIMUM RAMP ANGLE OF 15°.
3. ADD A MINIMUM OF 2" TO OVERALL TRANSPORTER HEIGHT WHEN SUPPORTED ON BUILT-IN JACKS.

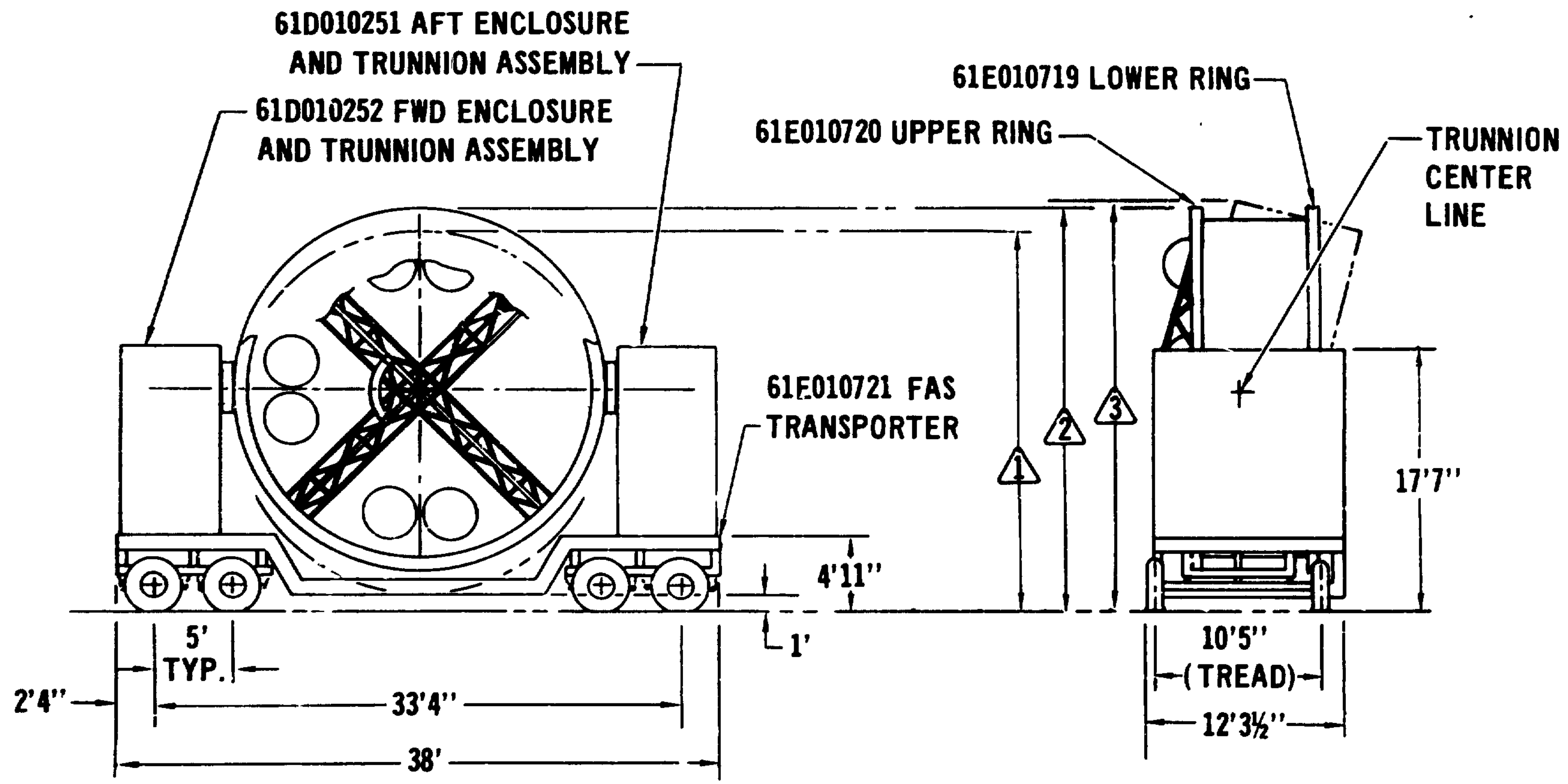
FIGURE 2.15-2 AIRLOCK IN VERTICAL TRANSPORTER



NOTES:

1. THE TRAILER COULD NEGOTIATE A MAXIMUM RAMP ANGLE OF 4°.
2. ADD A MINIMUM OF 2" TO OVERALL HEIGHT OF TRAILER WHEN SUPPORTED ON BUILT-IN JACKS.
3. MATED AM/MDA IN LAUNCH-AXIS-VERTICAL ATTITUDE REQUIRED INSTALLATION OF AUXILIARY WHEELS.

FIGURE 2.15-3 MATED AM/MDA IN HORIZONTAL TRAILER



NOTES:

1. 292.0" MINIMUM HEIGHT FOR OVER-THE-ROAD TRANSPORTATION.
2. 314.0" MINIMUM HEIGHT REQUIRED DURING FAS ROTATION FOR 61E010719 LOWER RING AND 61E010721 FAS TRANSPORTER FRAME CLEARANCE.
3. 321.0" MINIMUM FACILITY HEIGHT REQUIRED FOR 4.0" CLEARANCE OF 61E010720 UPPER RING AND FACILITY DURING FAS ROTATION.

FIGURE 2.15-4 FAS IN TRANSPORTER – LAUNCH AXIS HORIZONTAL

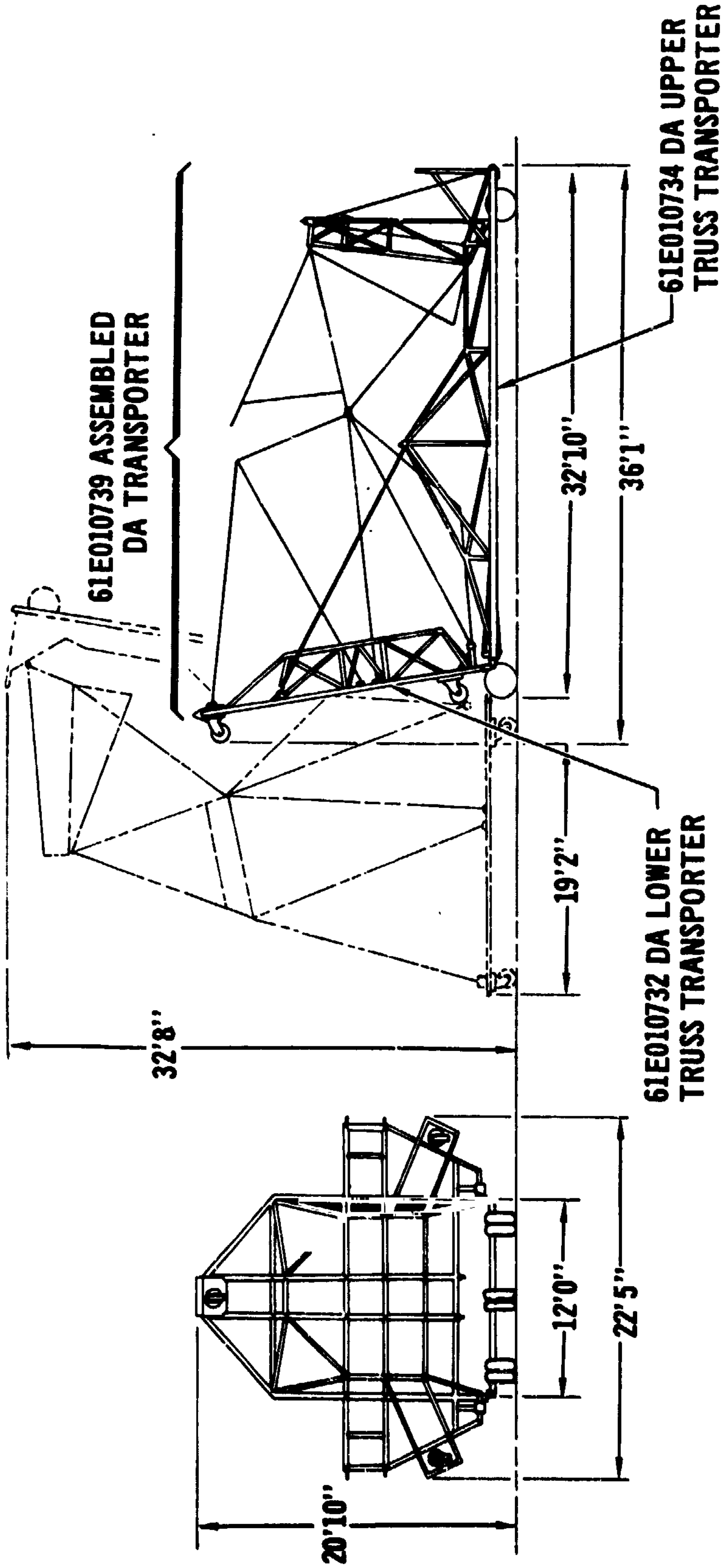


FIGURE 2.15-5 MATED DA IN TRANSPORTER

A. Mechanical GSE Summary - Mechanical GSE items produced or utilized on the Skylab Program in support of the Airlock and Payload Shroud vehicle segments are summarized below:

Airlock Module	New Designs	GFE From Other Programs
Prime Equipment Items	111	8
Ancillary Equipment Items	20	19
Payload Shroud		
Prime Equipment Items	13	11
Total No. of Mechanical GSE End Items	144	38
	182	

B. Handling and Transporation GSE Functional Descriptions - MDAC-E Document No. 61E000001, "Airlock GSE Index," provided a description of all prime GSE items.

The major AM, FAS, and DA handling and transportation GSE end items are described in the following paragraphs and illustrated by Figures 2.15-6 through 2.15-13. Major PS handling and transporation GSE items are described in MDC Report G4679, Section 5.1, "Payload Shroud Final Technical Report."

(1) Airlock Module Vertical Transporter and Associated GSE - The 61E010022 AM Vertical Transporter, Figure 2.15-6, which supported the AM in the vertical attitude module by utilizing the FAS attach point provided the capability for intersite movements and served as a final assembly fixture for the AM STS, tunnel, and truss segments. The 61E010005 Closure Assembly was a pressure bulkhead which simulated the S-IVB interface with the AM aft tunnel flexible extension bellows assembly. The 61E010726 Support Trusses stabilized the AM truss assemblies during ground handling operations. The 61E010045 Closure Assembly was a multipurpose design which functioned both as a pressure bulkhead at STS AMS Station 200.00 and as a vertical hoisting device for the entire Airlock Module. The AM Vertical Transporter was used to ship the AM Structural Test Article (STA-1) to Huntsville, Alabama, and Houston, Texas, via the Super Guppy. The Super Guppy pallet and

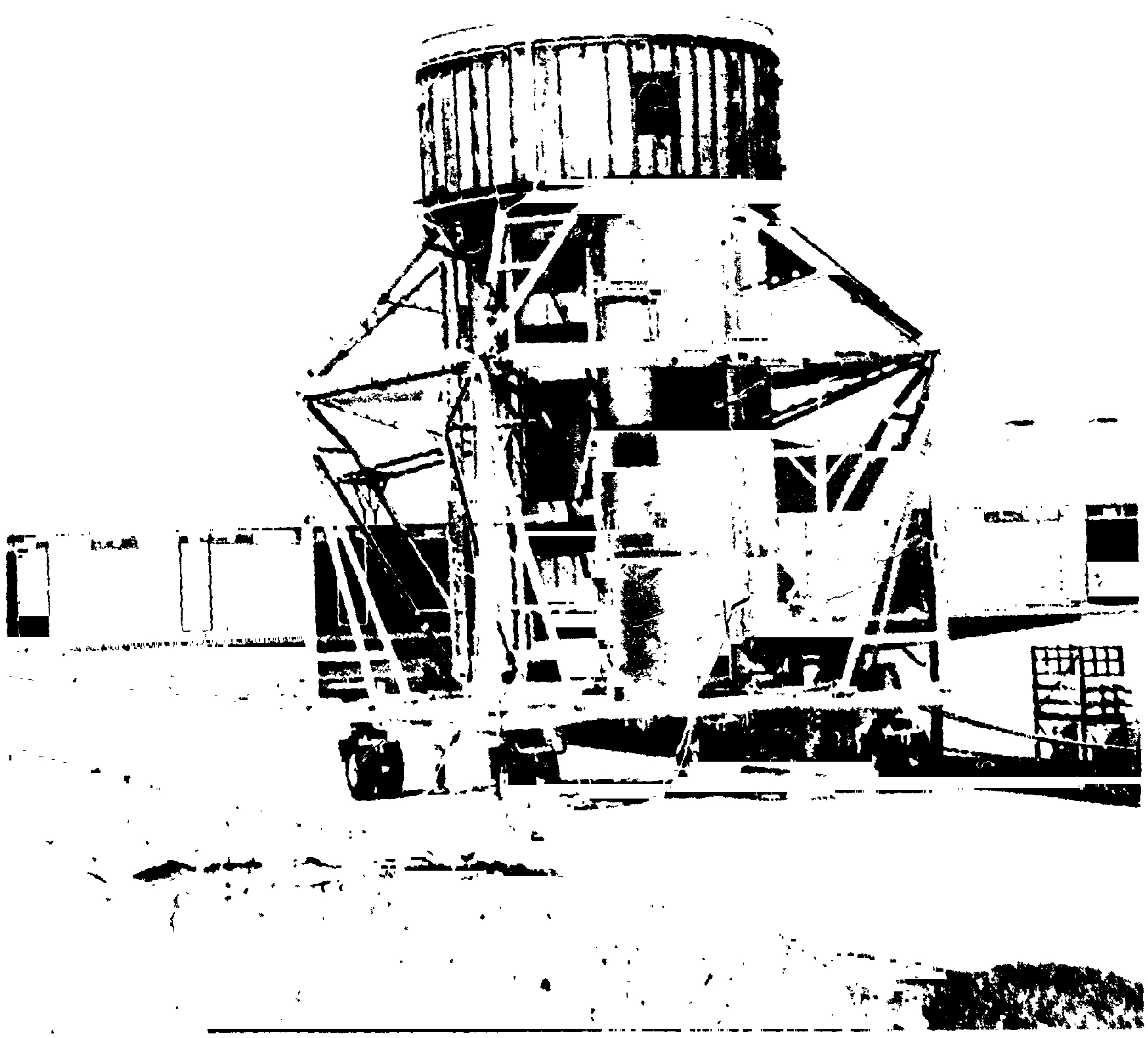


FIGURE 2.15-6 AM VERTICAL TRANSPORTER AND ASSOCIATED GSE

a cargo lift trailer, both GFE items, were utilized to provide roll-on/roll-off capability.

(2) Mated AM/MDA Handling and Transporation - The 52E010016 AM/MDA Transporter, Figure 2.15-7, was a pneumatic-tired, dual tandem wheel trailer capable of supporting the AM or mated AM/MDA in either the horizontal or vertical attitude. The transporter supported the flight article during systems build-up and testing activities in addition to providing inter/intra site mobility and airshipment capability.

The transporter configuration used to ship the mated AM/MDA Skylab Unit 1 to KSC by air via the Super Guppy aircraft is shown by Figure 2.15-8. The upper frame assembly, with the flight article, was disengaged from lower frame assembly and placed on a specially modified Super Guppy shipping/shoring pallet. Transfer of this assemblage into the aircraft was accomplished utilizing the lateral translation capability of a GFE cargo lift trailer.

The transporter was also used to ship the mated AM/MDA Skylab Unit 2 to MSFC via barge. The transporter, with its cargo, was towed to the St. Louis Terminal Dock, where the entire assemblage was lowered, via crane, onto a flat deck barge and then subsequently transferred to a covered barge.

(3) FAS Transportation and Handling - The 61E010721 Fixed Airlock Shroud Transporter, Figure 2.15-9 was a pneumatic-tired, dual tandem wheel trailer used to provide mobility for the FAS in either the horizontal or vertical attitude. Enclosed structures at either end of the trailer contained slaved, pneumatic-driven mechanisms to raise, lower, or rotate the FAS, which was secured between the 61E010719 and 61E010720 Upper and Lower Handling Rings. FAS airshipment capability was provided by the 61E010746 Air Shipping Pallet Assembly, Figure 2.15-10. This 43-foot-long truss frame structure replaced the standard Super Guppy pallet for FAS shipment and hence required certification by the FAA for flight worthiness. The 61E010746 interfaced with the 61E010719/720 Upper and Lower Handling Rings and with the GFE Cargo Lift Trailer (CLT). The CLT provided roll-on/roll-off loading capability into the Super Guppy airplane.

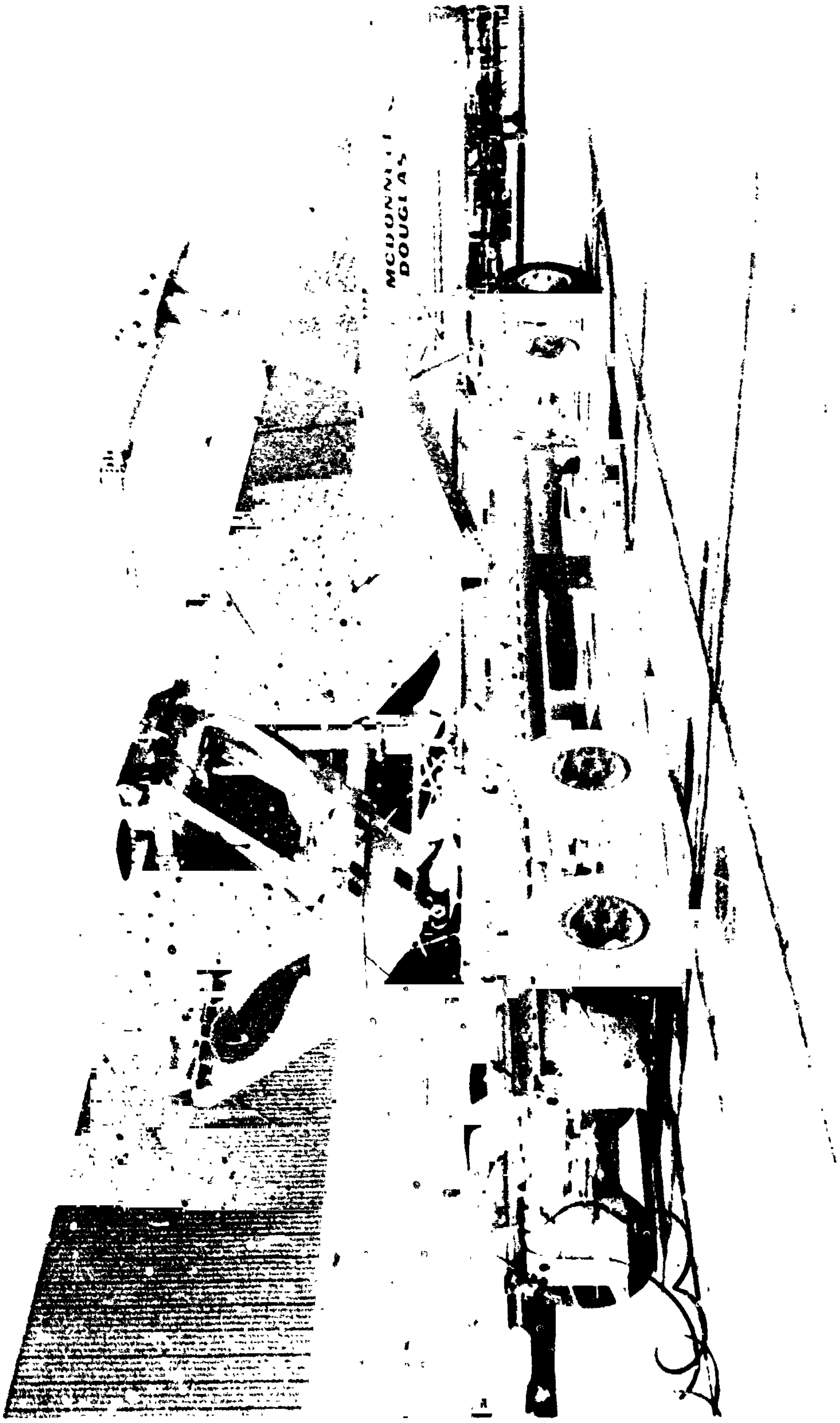


FIGURE 2.15-7 AM/MDA HORIZONTAL HANDLING TRAILER

FIGURE 2.15-8 MATED AM/MDA BEING LOADED ON SHIPPING PALLET

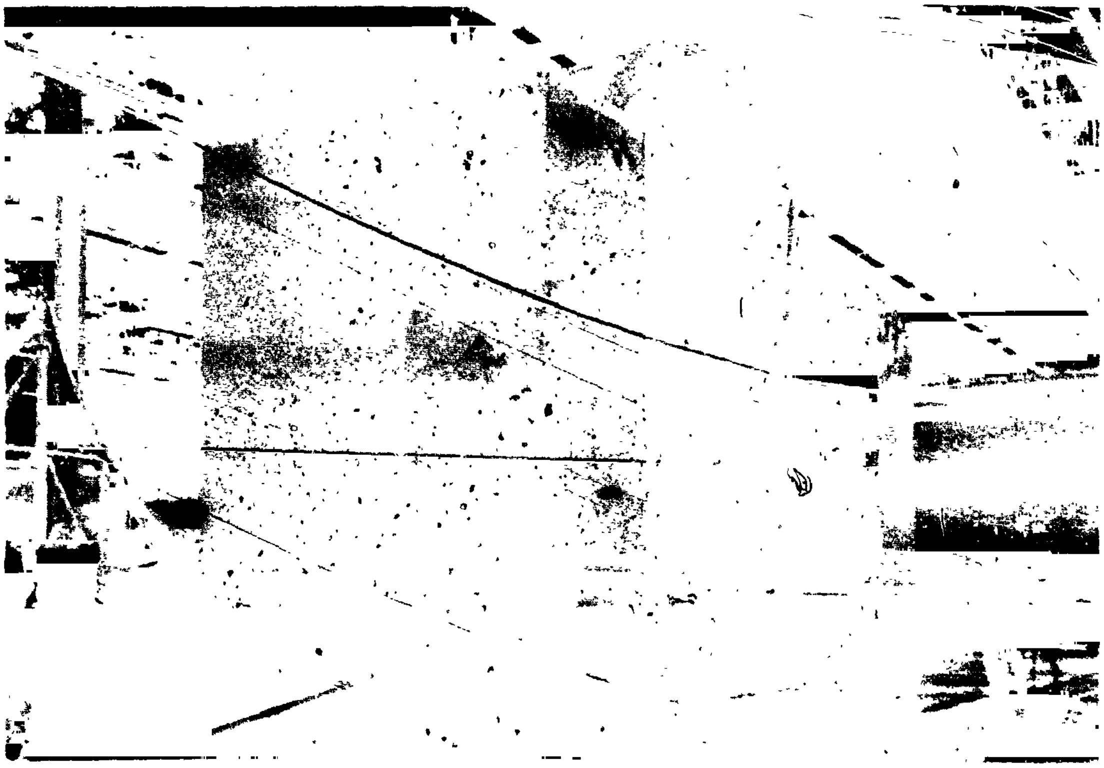


FIGURE 2.15-9 FIXED AIRLOCK SHROUD TRANSPORTER AND ASSOCIATED GSE (LAUNCH AXIS HORIZONTAL)

FIGURE 2.15-10 FIXED AIRLOCK SHROUD AIR SHIPMENT

(4) DA Transporation and Handling - The Deployment Assembly (DA) was a one plane of symmetry truss composed of an upper and lower frame assembly, neither of which were stable when detached from the FAS.

Lower and upper DA segment handling capability was provided by the 61E010732 and 61E010734 transporters, respectively (Figure 2.15-11 A and B). The 61E010733 lower DA retaining ring, attached to the DA fixed truss struts, structurally simulated the FAS and maintained the spatial relationship of the FAS/DA interface connection. The ring in turn interfaced with the 61E010732 transporter, together providing a stable platform for handling the lower, or fixed truss, DA. The 61E010734 transporter provided a stable platform for handling the upper, movable, DA truss.

Assembled DA handling and transportation capability was provided by the 61E010739 transporter.

Figure 2.15-11C illustrates the unique method employed to satisfy the assembled DA handling requirement, wherein the 61E010732 and 61E010734 transporters were designed to interface with each other thus forming the 61E010739 transporter. The 61E010749 trunnion brace was a straight strut required to maintain the proper spatial relationship of the DA movable truss trunnions.

Utilization of the 61E010739 assembled DA transporter for inter-site air transport by Super Guppy and handling of the assembled DA, in conjunction with the GFE Super Guppy pallet and cargo lift trailer is illustrated in Figure 2.15-12. The 61E010739 unit was also used for intrasite transfers with the DA in the launch-axis-horizontal attitude and, in addition, could be rotated 90 degrees to place the assembled DA in a launch-axis-vertical attitude.

(5) FAS/AM/MDA/DA/PS Stack Handling and Transporation - The FAS/AM/MDA/DA PS flight article segments were mated and tested in the MSOB. This assemblage then required transfer to the VAB. A modified GFE item, the SLA transporter, was used to accomplish the transfer of the mated FAS/AM/MDA/DA/PS segments from the MSOB to the VAB. This load was twice the original rated capability of the SLA transporter, but by modifying the unit an uprated capability was obtained, thus saving the cost of a new GSE item. The 61E010730 hoist assembly, Figure 2.15-13, was used to lift the stack from the MSOB work stands and mate it to the Orbital Workshop in the VAB.

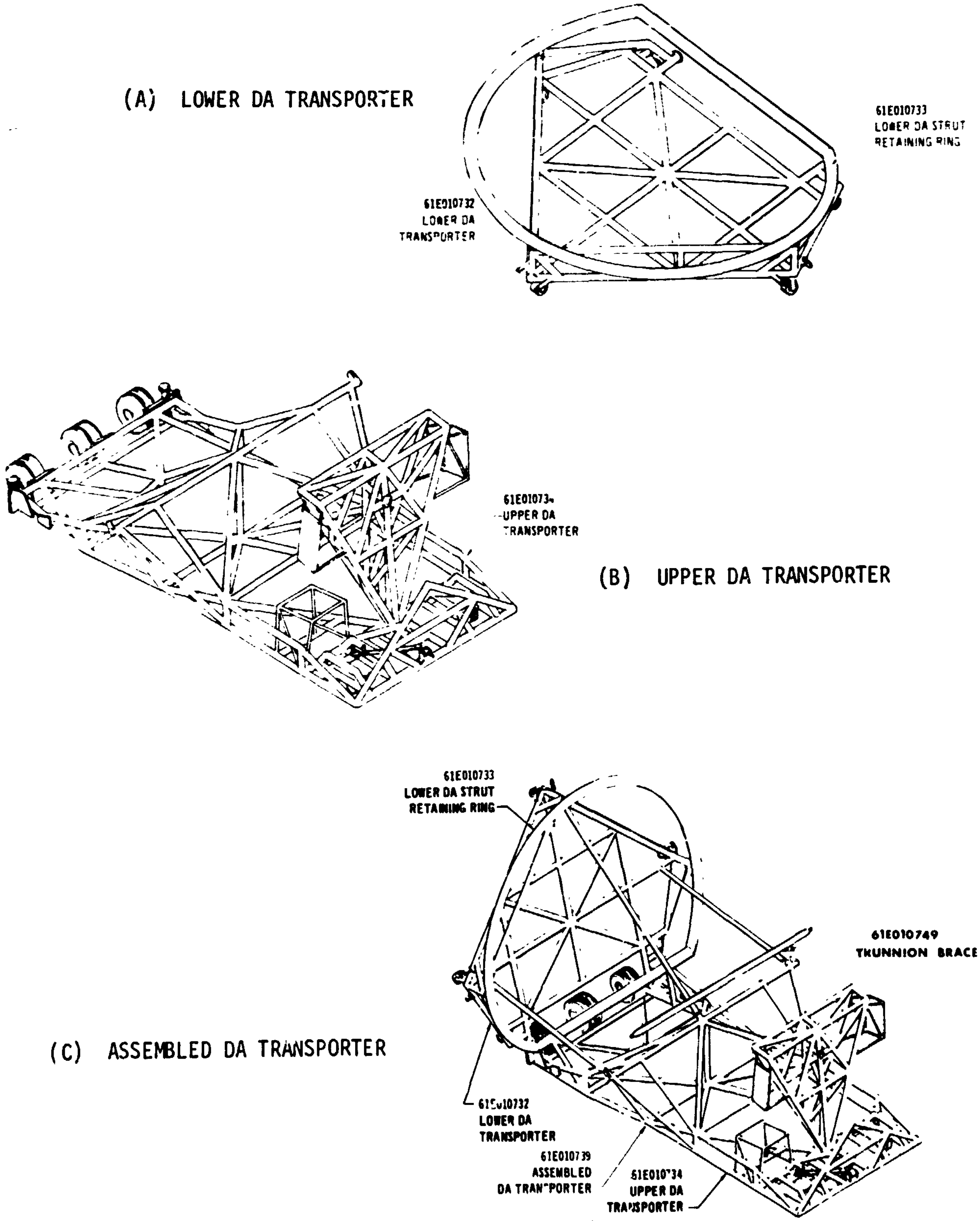


FIGURE 2.15-11 DA TRANSPORTER

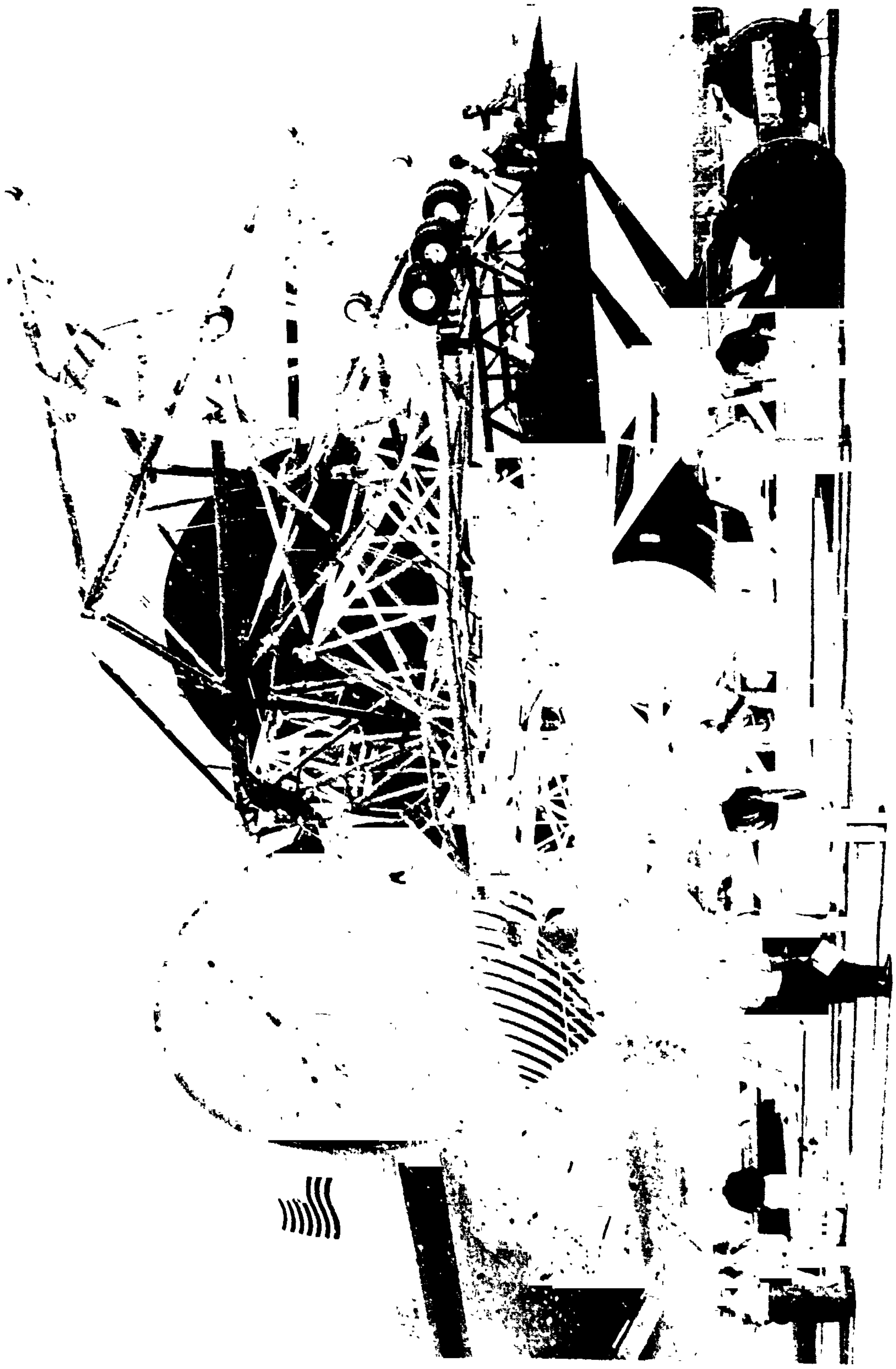


FIGURE 2.15-12 DEPLOYMENT ASSEMBLY AIR SHIPMENT

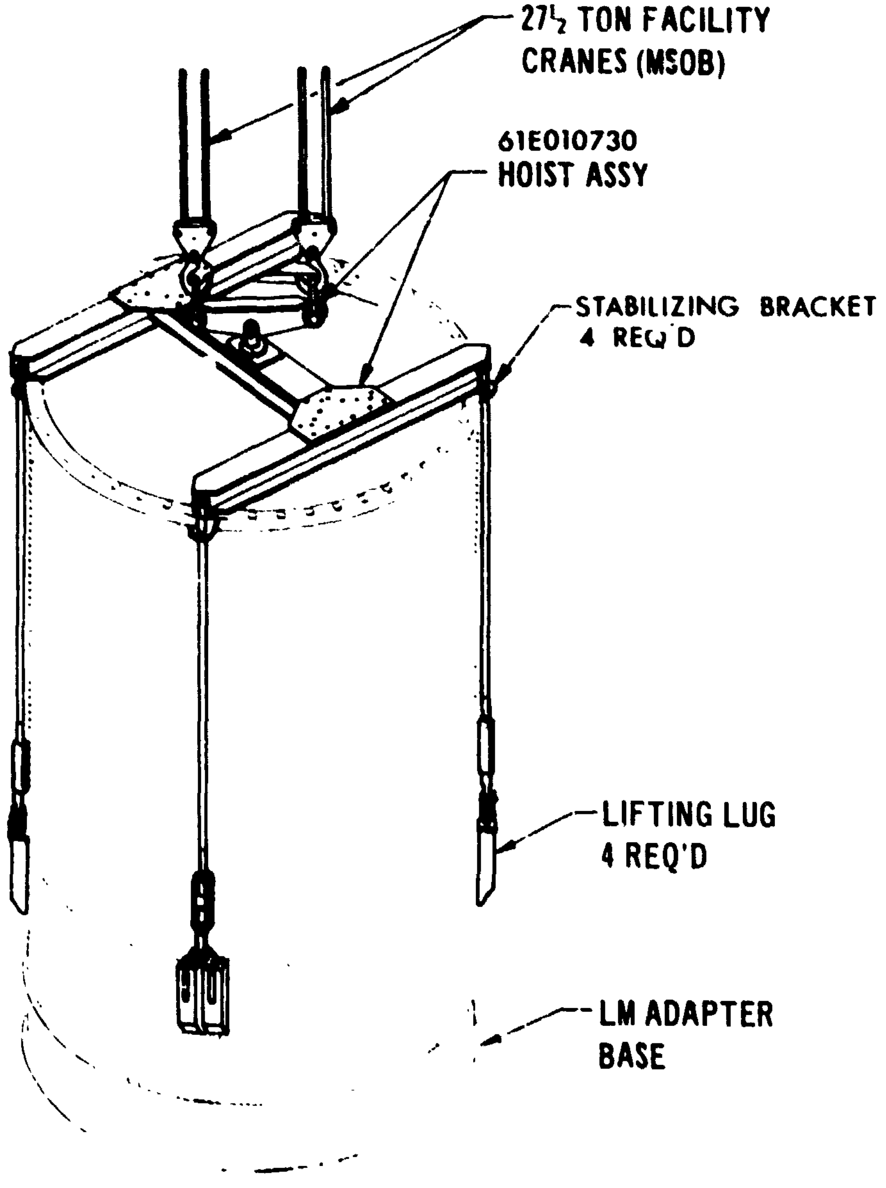


FIGURE 2.15-13 FAS/MDA/AM/DA/PS CYLINDER STACK HANDLING

Skylab 1 Stacked Configuration Access and Internal Hoisting Provisions - The complex arrangement of work platforms required inside the PS for access to test and service points on the AM/MDA/DA is illustrated in Figure 2.15-14. These platforms were attached to PS ring structures one segment at a time to build the assemblage shown. Not shown are the various work/access platforms used inside the AM/MDA. The design of these platforms was patterned after those used on the Apollo Program.

Figure 2.15-15 shows a partial installation of the platforms during a trial fit check conducted at the contractors Huntington Beach facility to verify the interfaces between the platforms and the PS. A second trial fit was conducted at JSC with the AM/MDA in place to verify platform to flight hardware clearances.

2.15.3.2 Electrical/Electronic GSE

This category of GSE provided the capability of supplying, monitoring, recording, and displaying all electrical, pneumatic, hydraulic, and mechanical test parameters utilized or required during all phases of testing and checkout.

Electrical GSE items generally were directly relatable to the flight system. Electrical GSE systems required for the conduct of integrated vehicle testing were as follows:

- Electrical Power and Control System GSE
- Instrumentation and Data Acquisition System GSE
- Communications, Command and TV System GSE

Other examples of electrical GSE items/categories included acceptance and pre-installation test equipment, interface simulators, cabling and power distribution equipment.

A. Electrical/Electronic Summary - The following is a tabulation of electrical GSE items utilized in support of the Airlock Module and Payload Shroud.

	New Design	GSE From Other Programs
Airlock Module		
Prime Equipment Items	41	54
Ancillary Equipment Items	53	60
Payload Shroud		
Prime Equipment Items	3	4
Total No. of Individual Electrical GSE Items	97	118

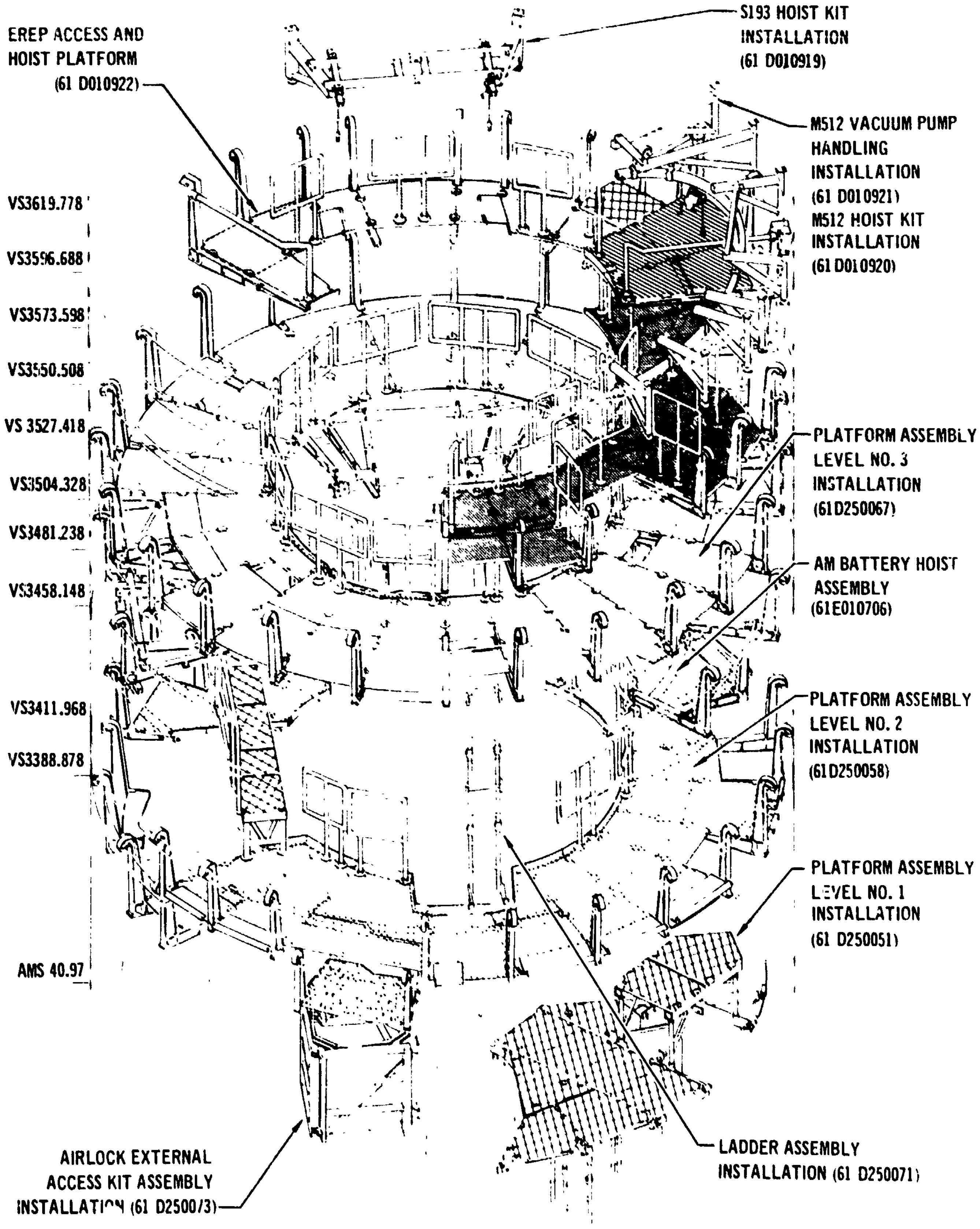


FIGURE 2.15-14 ACCESS AND HOISTING PROVISIONS

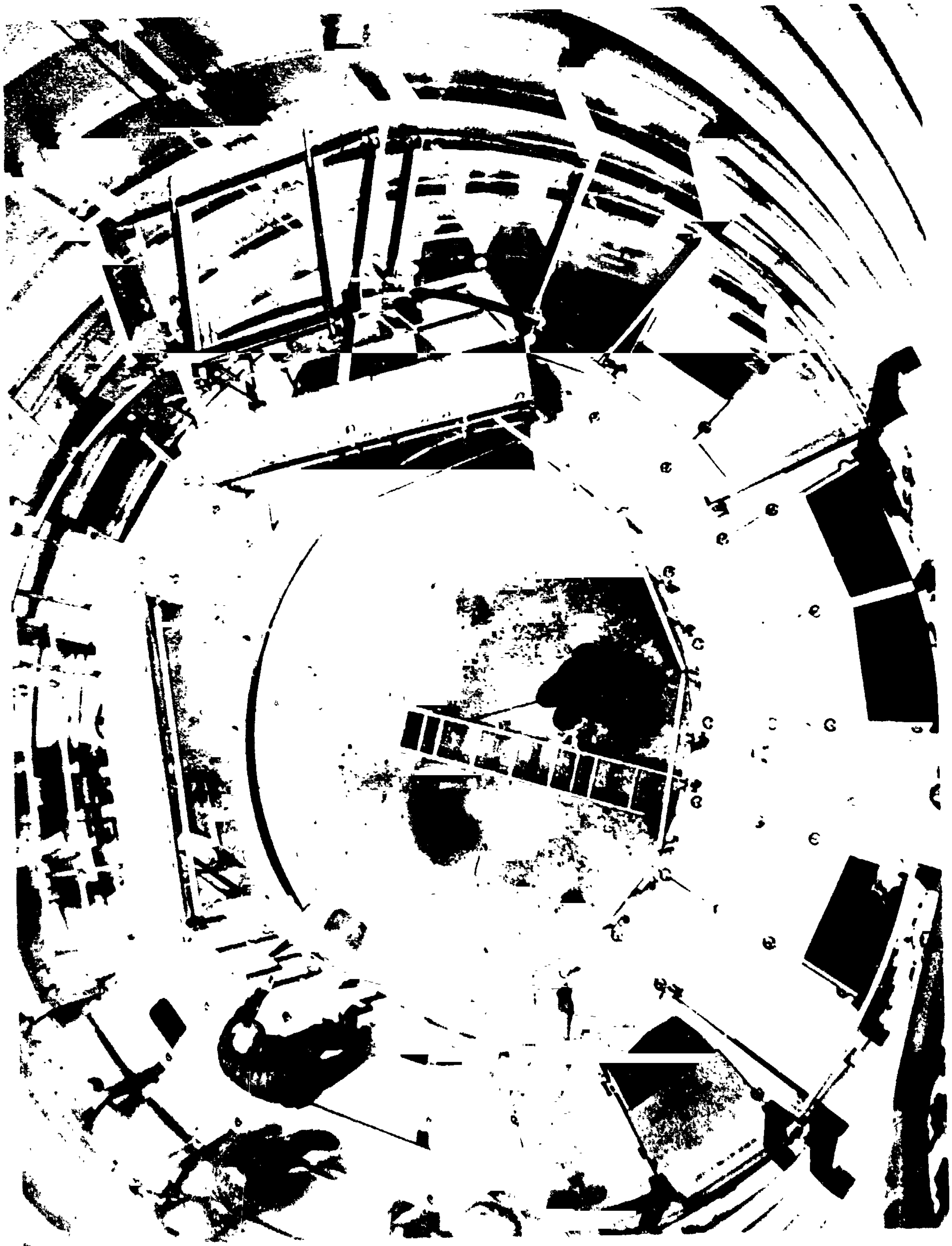


FIGURE 2.15-15 PAYLOAD SHROUD ACCESS PLATFORM TRIAL FIT

The interrelationship and system configurations of the electrical GSE end items and interfaces with the flight vehicle were defined on MDAC-E Drawings 61E200001, "Cabling Installation - Factory Test Area," 61E200002, "Cabling Installation - KSC," and 61D200057, "Facility Interface Requirements, - AM/MDA (part of 52E200015, "Equipment Installation - SST"). Schematics for the individual end items were defined in the end item detail drawing and in the Operational and Service Manual (D5 Series SEDR) prepared for each operational unit.

B. Electrical/Electronic GSE Functional Description - MDAC-E Document No. 61E000001, "Airlock GSE Index," provided a functional description of each prime equipment item. Figure 2.15-16 illustrates the usage of major items of electrical/electronic GSE for St. Louis Spacecraft Systems Tests. This test configuration was also representative of KSC configurations for MSOB, VAB, and pad testing. Major differences between St. Louis and KSC testing were the use of:

- Apollo Acceptance Checkout Equipment (ACE) used at KSC in lieu of the PCM telemetry Ground Station (52E440011).
- Remote DCS control at KSC through use of the DCS prelaunch control assembly (61E190011).
- Open loop testing at KSC through use of the RF Interface Rack (61E190015).
- CSM load simulation at KSC through use of the CSM Load Simulator (61E040012).

The following describes the major GSE illustrated in Figure 2.15-16.

(1) Electrical Power System GSE

- 61E230013 - Power System - Ground Control - This unit was a two-bay mobile rack which supplied DC ground power to the Airlock REG Bus 1, EPS Bus 1, REG Bus 2 and EPS Bus 2. This system contained the necessary meters for measurement of the Airlock power system electrical parameters, which could also be recorded using three 52E230005 Analog Recorders which interfaced with the rack.

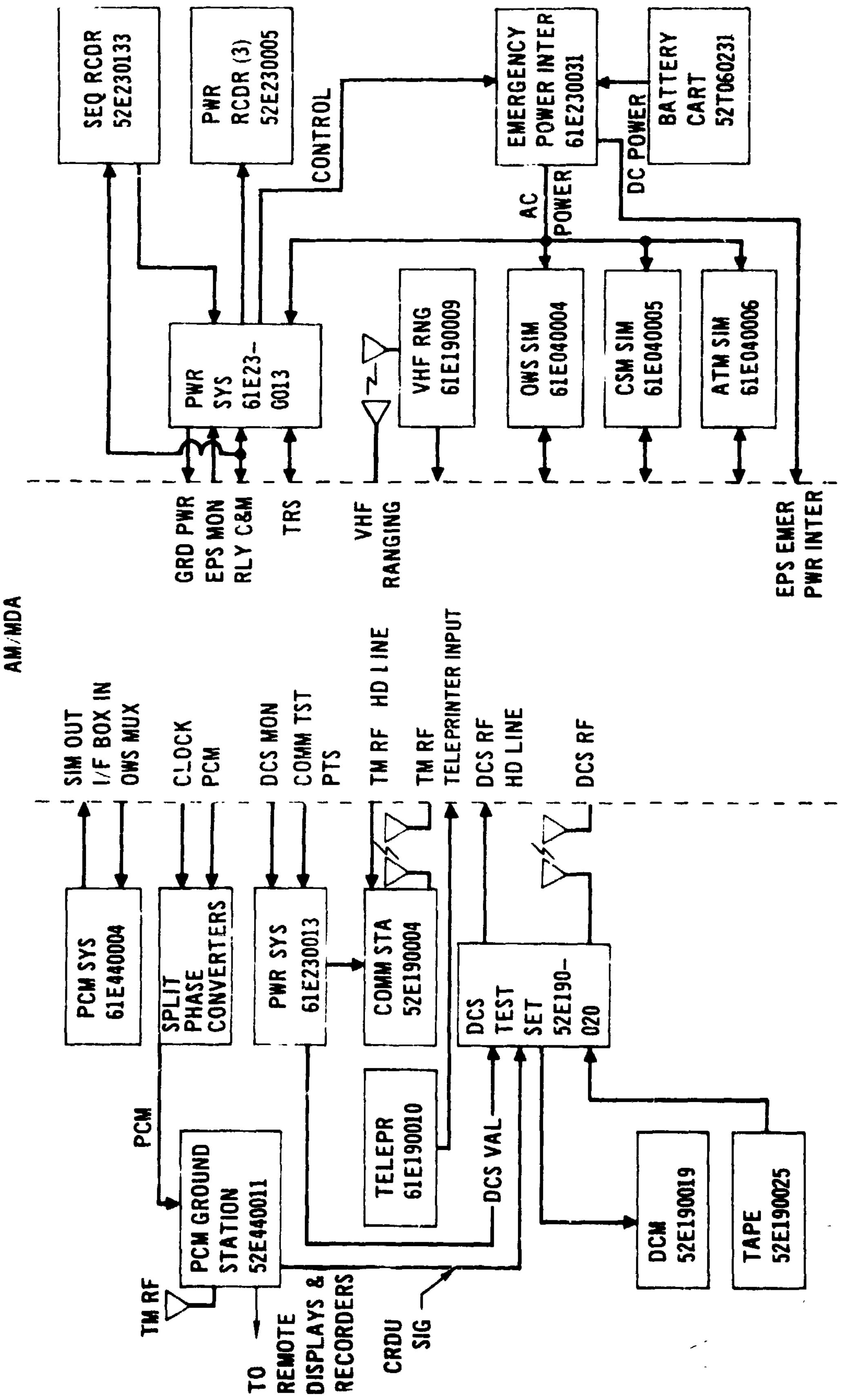


FIGURE 2.15-16 AM/MDA ELECTRICAL/ELECTRONIC GSE – MDAC-E

The system included the following:

(a) Two (2) Model 14700-102 Basler Power Supply Units (0 to 36 volts, 0 to 100 amps)-Power Supply #1 supplied REG Bus 1 and EPS Bus 1, Power Supply #2 supplied REG Bus 2 and EPS Bus 2. Each power supply had remote sensing.

(b) One (1) 61D230051 DC Power Control Panel - This panel controlled the two (2) power supplies, contained meters to measure the Airlock power system parameters, monitored critical relays before powering the Airlock and provided the control for 100% reset of the Airlock amp-hour meters.

(c) One (1) DVM - Used for accurate measurements of individual electrical parameters.

(d) One (1) 52E270048 Electronic Timer Control Panel - Controlled and monitored the Time Reference System (TRS) electronic timer during systems test.

(e) One (1) Power Supply (0 to 36 volts, 0 to 10 amps) - Used to supply power for all GSE functions which did not interface with the Airlock.

(f) One (1) 61D230087 Relay Monitor Panel - Monitored the status of the slow release relays in the Airlock and isolated any improper operation to an individual relay.

(g) One (1) 61D230100 Relay Isolation Monitor Panel - Provided status of noncritical relays prior to powering the Airlock.

(h) One (1) Patchboard Assembly. Routed selected signals to the 52E230005 recorders.

(i) One (1) 61D230131 DA-PS Panel Assembly - Monitored outputs of the Sequential Relay, PS Relay and the DA Relay Panel Assemblies and provided commands to these panel assemblies to simulate the DA limit switch closing and PS lanyard interlock switch operation.

- <u>52E230005 - Power System - Recorders (3 Units)</u> - This was a single bay rack mounted on casters which contained an eight channel analog recorder, eight DC amplifiers and eight high gain pre-amps. This unit interfaced with the 61E230013 Ground Control Power System and provided a method for obtaining a permanent record of the power conditioning group functions.

- 52E230133 - Recorder - Sequence Relays - This was a single bay rack, mounted on casters, containing a 100 channel Brush Model 14-3615-20 event recorder and a patchboard to provide for selection of signals. This unit interfaced with the Airlock and the 61E230013 Power System Ground Control Unit to record and measure the operation of the Airlock slow release relays.

(2) Instrumentation and Data Acquisition GSE

- 52E440011 - PCM Telemetry Ground Station - The primary function of the PCM Telemetry Checkout Ground Station was to provide a means for ground evaluation of various functions on the Airlock vehicle by extracting and decommutating telemetry data transmitted by the Data Acquisition System (DAS) in serial PCM form.

  Transmissions to the ground stations were via both land-lines or RF carriers during test and preoperational checkout.

  The DAS commutated and multiplexed spacecraft analog, bi-level, and time data into a serial PCM output signal, which was transmitted to the ground station via a RF transmitter in either a real time or delayed time mode. In the delay time mode, spacecraft data was tape recorded, and then on command played back for use by the ground staion.

  The ground station provided various methods for recovering and processing spacecraft PCM transmissions. Transmissions could be recorded on magnetic tape for later use; processed and recorded; or processed, recorded and displayed for real-time use. The ground station reconstructed the PCM data output from the flight vehicle into data trains of optimum signal characteristics, decommutated the data, and processed the data into the desired binary, binary-coded-decimal (BCD), or analog form. The processed data was then displayed and/or recorded for analysis of the operational status of the vehicle functions being monitored.

- 61E440004 - PCM Input Simulator - The PCM Input Simulator was configured to fulfill two distinct test situations. One was to supply all the required stimuli to the DAS during module testing as required to verify that the flight modules were wired and functioning properly. This was done prior to module installation on the vehicle and before system validation testing in order to allow sufficient time to correct any discrepancies. The second test situation was that this unit was to simulate the signals supplied to, or received from, the AM DAS across the AM/OWS and AM/MDA interfaces. This was done during systems validation tests at St. Louis and again at KSC to insure electrical compatibility at cluster mate-up.

  The simulator duplicated the low level (0 to 20 MV) and high level (0 to 5V) data channels, and the discrete (0 to 28 VDC) channels that crossed the AM/MDA interface. It simultaneously supplied inputs to a set of five (5) high level and seven (7) low level multiplexers contained in the simulator which duplicated the OWS complement of multiplexers. The multiplexer timing and drive inputs from the AM and the DAS outputs to the AM were cabled directly to the OWS/AM interface. The rack internal wiring and external cables for these signals duplicated as closely as possible the actual OWS wiring.

  During modular level testing, the simulator supplied the DAS with the signals that normally crossed the AM/MDA and AM/OWS interfaces as well as simulated the T/M data channels that crossed the AM/ATM and AM/FAS interfaces. In addition, it supplied stimuli to all the data channels that originate on the AM. It also had the capability to actuate the PCM system control relays (control of tape recorders, DC-DC converters, transmitters, etc.) to show that the proper relays operated either by presenting a voltage level or contact closure at the test point panel.

(3) Communication and Command System GSE

- 52E190004 - Communications Test Station - The Communication Test Station (CTS) consisted of two racks of standard and special test equipment. The special test equipment provided signal routing, interfaces with standard test equipment, and special measurement

capability where required. The CTS was used primarily for VHF RF tests on the AM system but had limited audio test capability which could be used to check out the AM audio system lines, if required. The CTS provided a source of general purpose standard test equipment which could be used with special breakout boxes for specialized tests, if required.

- 61E190009 - VHF Ranging Test Set - The VHF Ranging Test Set consisted of three racks of special test equipment. The major special test equipment items were the VHF Ranging Test Assembly (VRTA), the VHF Signal Conditioner (VHFSC) and Communication Patch Panel (CPP). The remaining items were standard test equipment such as oscilloscopes, counters, voltmeters, power meters, RF power amplifier, power supplies, signal generators and VHF receivers.
- 61E190004 - CRDU Monitor Panel - The Command Relay Driver Unit (CRDU) Monitor Panel was used to decode the telemetry outputs from the CRDU aboard the Airlock, as received from the TM Ground Station, QLDS or ACE, and displayed the decoded message utilizing a digital printer. Range time was also displayed on the printout while the message received, validity and command channel inhibit signals were displayed by lamp indications.
- 61E190010 - Teleprinter Test Set - The AM Teleprinter Test Set was a suitcase tester containing a cassette tape programmer, memory logic, timing logic, shift register, interface line drivers, and control logic. The subject tester simulated the AM Interface Electronics Unit (IEU) interface with the AM Teleprinter and generated the required signal formats to test the AM Teleprinter for proper operation. Test points were provided to monitor interface characteristics.
- 61E190011 - DCS RF and Control Assembly - The DCS RF and Control Assembly, located on the LUT for VAB and Pad testing, was used to provide updating of Airlock systems via the Airlock digital command link and the OWS umbilical. The subject unit also housed the split phase converters for PCM data transmission to the O&C Building data hardline systems. The 61E190011 was remotely controlled by the ACE. Command data from the 52E190020

DCS Test Set, located in the O&C Building was received by the 61E190011 via a 70 KHz FM subcarrier link.

- 61E190015 - RF Interface Rack - The RF Interface Rack consisted of an RF patch panel and 40-watt UHF amplifier. The patch panel provided an interface between the AM DCS, Telemetry, VHF Ranging RF GSE, and the O&C Building RF Transmission System. The 40-watt UHF amplifier was used to boost the DCS Command RF to a sufficient level for open-loop RF transmission to the VAB and Pad for open-loop command systems tests.
- 52E190019 - Digital Command Monitor - The Digital Command Monitor (DCM) was a single rack of GSE used to provide monitoring of the operations of the Airlock Digital Command System (DCS) during all DCS checkout phases. In addition, the unit provided a means of "calibrating" the DCS test set when these two test units were interconnected.

  The rack was comprised of five subunits; the DCS receiver and detector, a decoder, comparator, and a high-speed on-line printer.

  The receiver and detector were basically the same units as employed in the airborne DCS, requiring minor packaging and mounting modifications. The decoder was capable of decoding and storing an entire message. The decoder provided outputs for 32 discrete command messages, and a GSE validity pulse. These outputs were introduced into the comparator where like outputs originating in the Airlock DCS were compared for correct airborne operation. The message content was recorded on a high-speed printer both in a no-go and continuous mode of operation.
- 52E190020 - Digital Command System Test Set - The DCS test set was used to perform PIA and systems testing on the Airlock Digital Command System in all test areas. When used with the 40-watt amplifier in 61E190015, the test set was capable of conducting open-loop RF tests between the O&C Building and the VAB/Pad.

  The DCS test set was composed of a combination of commercial standard test equipment and specially designed circuitry. The commercial equipment consisted of an RF signal generator, a digital multimeter, a counter and an oscilloscope. Special digital logic

circuitry was provided to generate a message, compare the various functions within the DCS to those generated, and read out messages.

The DCS test set used at KSC contained a 70 KHz subcarrier oscillator which was used to provide a carrier for the 1 and 2 KHz command data sent to the remote 61E190011 DCS RF and control unit located on the LUT during VAB and Pad tests.

The DCS test set also contained the 61E190004 CRDU Monitor Panel used to monitor CRDU operation.

(4) Simulators - Four simulators were designed to simulate input and output signals at the Airlock interfaces. The simulators were divided into functional sections to accommodate the various test areas and test configurations as follows:

61E040004 - Rack 500 - Solar Array Wing Power Simulation (4 PCG's)
- Rack 501 - Solar Array Wing Power Simulation (4 PCG's)
- Rack 502 - OWS Control, Monitor and Load Simulation

61E040005 - Rack 503 - CSM Power, Load and Audio Simulation
- Rack 504 - MDA Control, Monitor and Load Simulation

61E040006 - Rack 505 - ATM Power, Loads, Control and Monitor Simulation

61E040012 - Rack 506 - CSM Load Simulator

One additional simulator, 61E440004 Input Simulator - PCM System (Rack 511), was provided to simulate the OWS instrumentation signals. This simulator is described in the Instrumentation and Data Acquisition System GSE section.

All simulators designed by MDAC-E had, with a few exceptions, Level II capability. This simulation level provided the capability to functionally check the AM operation at the interface under nominal static conditions, but did not exactly duplicate the actual signal in terms of EMI characteristics, impedances, etc. The exceptions were the solar array power simulation, CSM audio center simulation, and CSM load simulation.

The Solar Array Power was simulated with characteristics very similar to a solar array so development tests could be conducted to verify PCG performance. The CSM Audio Center Simulation was accomplished using a CSM audio center such that characteristics were

precisely duplicated for speaker intercom and audio load compensator testing. The CSM total load simulation was accomplished using flight type EMI filters and inverters.

The control, monitor and load sections of the simulators were designed using two (2) panel configurations. A control and monitor panel assembly contained switch-lights, lights, relays, test points, and feed through patch wiring. This panel, with appropriate patching, was used in each of the interface simulators. A load panel assembly contained load resistors and feed through patch wiring.

The 61E040005 CSM Power Simulation section routed DC power from power supplies to one of three predetermined CSM fuel cell isotherm simulators. A panel, through circuit breakers and switches, provided the capability to program fuel cell #1 or #2 simulated outputs to AM Bus 1 or AM Bus 2 and/or the CSM simulated load. The isotherms were generated by straight line approximations and the CSM loads were simulated as resistive loads only. Each fuel cell simulator was designed to transfer 2.5 KW of power and the 61E040005, in conjunction with an external load bank, would accept 2.5 KW of power transferred from the AM. The 61E040005 also provided the capability to select CSM or AM single point ground (in conjunction with AM selection) and monitor AM/CSM bi-directional current and voltage transfer.

The 61E040005 Audio Center Simulation section, which electrically simulated the Apollo Command Module (CM) audio system, consisted of an Apollo Audio Center (P/N ME473-0086-0002) and a control panel providing the necessary control of the audio center to duplicate interface audio levels, impedances, etc. In addition, it provided switch closures and displays for antenna control signals and "CALL" signals crossing the CSM-AM/MDA interface.

The 61E040006 ATM Simulator fed DC power from simulator power supplies to the ATM regulator droop characteristic (D/C) resistor located in the simulator. This provided the capability to program the output of D/C resistor No. 1 or No. 2 to AM Bus No. 1, AM Bus No. 2 and/or the ATM load bus. The droop characteristic resistor simulated the droop characteristics of the ATM regulator. Each bus

of the unit had the capability to provide 2.5 KW of power for transfer to the AM. The unit, in conjunction with an external load bank, would accept 2.5 KW from the AM. It also provided the capability to monitor bi-directional AM-ATM current and voltage transfer.

The 61E040004 Solar Array Wing Simulator (SAWS) was a versatile electrical power system simulator developed and manufactured by Spectrolab, Sylmar, California, per MDAC-E Procurement Specification (61P040001) requirements. The SAWS system was a precision high-current power supply in which the I-V (current/voltage) curve of the output could be modulated to simulate the electrical output of the OWS solar array wing during an earth orbit. The I-V curve could be controlled manually or by any of four stored programs, each simulating the electrical output characteristics of a specific earth orbit.

The basic SAWS physically consisted of two separate units; a variable output, 0 to 125 VDC, 32 ampere power supply unit and a control unit. A number of SAWS could be combined and interconnected to form a SAWS system of any size. The individual SAWS could be operated independently in such systems or interconnected in a master-slave configuration in which one master control unit controlled the slaved control units of the other power supplies.

The power supply unit consisted of a large power transformer, a circuit card containing the majority of electronic components, ten water cooled heat sinks on which six output series regulators and miscellaneous components were installed, and miscellaneous large capacitors, contactors, and relays. A water inlet and outlet connection was provided on the rear of the unit for connection to a cooling water supply. The power supply contained a very sensitive over-load protector which protected the power supply components from AC overvoltages and limited the maximum output to 125 volts for AM PCG protection.

The control unit contained the control and monitor functions for selecting a manual or automatic program for controlling the output of the power supply. In the manual mode this assembly had the capability to program the power supply such that the output would be a family of curves having open circuit voltage (VOC) intercepts

between the limits of 60V and 125 volts and short circuit current (ISC) intercepts between the limits of .5 amps and 32 amps. The intercepts (VOC and ISC) were manually selected set points. The power supply would then generate a single V-I curve which had the VOC and ISC intercepts at the set points. In the automatic mode, the set points (VOC and ISC) were automatically selected. The control unit generated a family of V-I curves which had set points (VOC and ISC) controlled by the program boards within the unit and in conjunction with the orbital timer, the power supply generated a power versus orbit position power profile. This power profile simulated the energy available at the AM/OWS interface from the solar array wing for one complete orbit with orbit length, beta angle and stabilization characteristics specified. The control panel provided the capability to select four (4) different orbit programs.

The 61E040012 CSM Load Simulator was designed to operate in conjunction with the 61E040005 CSM simulator and contained a CSM EMI filter and power inverter. This simulator provided a very close approximation of the CSM impedance in order to accurately load the AM PCG's. By loading the AM in this manner an accurate analysis of the power systems performance was accomplished.

2.15.3.3 Servicing and Fluids GSE

All fluid and gas commodities necessary for testing, servicing, flushing, purging, conditioning, and decontamination were categorized as servicing and fluids GSE. Fluids GSE end items functioned alone or as elements of a particular system. In many cases, the same end items were arranged in different combinations with one another to accomplish specific test functions.

The interrelationship and system configurations of the various fluid GSE end items and the interfaces with the flight vehicle were defined in the respective Engineering Support Data Documents, or "SEDR's," relative to AM/MDA fluids/gas systems testing at MDAC-E, and by MDC Report E0592 "AM Fluids GSE and KSC Test and Servicing Requirements Compatibility Document", which defined 62 individual fluids/gas systems test and servicing configurations required to support the AM/MDA at KSC.

The major servicing and conditioning systems were categorized as follows:

- O_2/N_2 Gas Servicing System GSE
- Ground Cooling System GSE
- Water Servicing System GSE
- Altitude Chamber Fire Suppression GSE system

Examples of other fluids GSE end items/categories include pre-installation acceptance test benches for high and low pressure gas fluid, and cryogenic component analysis, mobile LN_2/GN_2 high volume, high pressure converters, portable multirange calibration kits, transporter environmental control systems, and hand-held leak detection units.

A. Servicing and Fluids Summary - The following is a tabulation of the individual fluids GSE end items produced by MDAC-E in support of the Airlock Module and Payload Shroud.

Airlock Module	New Designs	GFE From Other Programs
Prime Equipment Items	38	58
Ancillary Equipment Items	37	26
Payload Shroud		
Prime Equipment Items	0	0
Total No. of Individual Fluids GSE End Items	75	84 (53% of total)
	159	

B. Servicing and Fluids GSE Functional Description - MDAC-E Document No. 61E000001, "Airlock GSE Index," provided a functional description of each prime equipment item. A description of the major systems is presented in the following paragraphs. There was no servicing and fluids GSE for the PS.

(1) O_2/N_2 Gas Servicing System - Shown in Figure 2.15-17 provided the capability for separate or simultaneous servicing of the Airlock O_2 and N_2 tanks at the pad from a remote control station located in the Launch Control Center as well as providing the regulated nitrogen for purging the AM/MDA prior to launch. The tanks were serviced with 6085 pounds of O_2 and 1623 pounds of N_2 using 4000 psig servicing system. The system which was physically located on Level 260 and Swing Arm #7 on the Launch Umbilical Tower, consisted of a 61E180032 Regulator Panel, a 61E180023 High Pressure Servicing Junction Box, and associated interfacing hose and hardline assemblies.

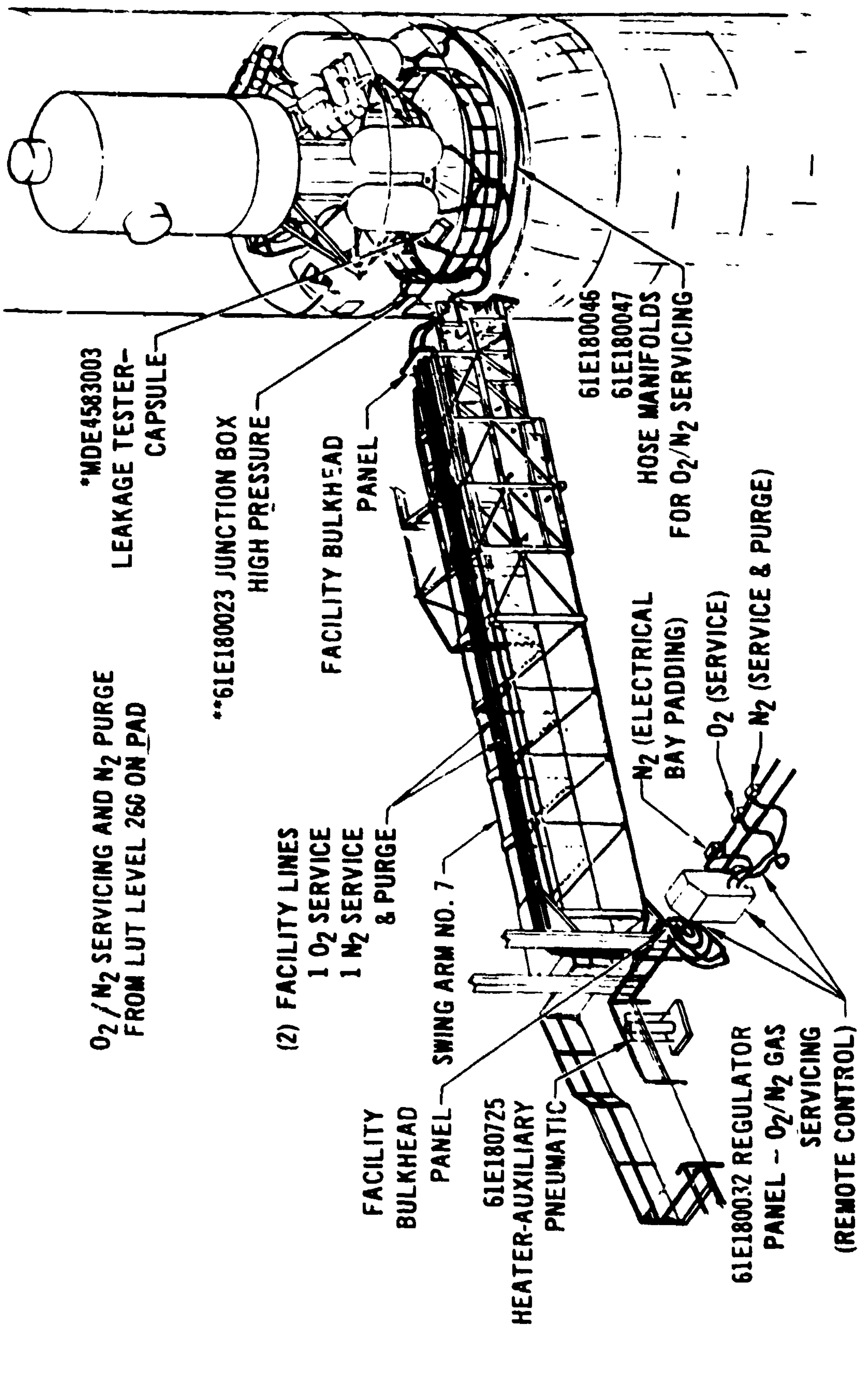


FIGURE 2.15-17 O_2/N_2 SERVICING AND AM/MDA N_2 PURGE

During vehicle build-up and test operations in the VAB, this system was also used to perform AM O_2/N_2 tank high pressure checks and O_2 flow controller tests. A schematic of this system is shown in Figure 2.15-18.

(2) Ground Cooling System - The heat load generated by the AM/MDA electrical/electronics systems was required to be dissipated during vehicle test operations at St. Louis, the MSOB, VAB or at the pad. The AM/MDA heat exchanger incorporated separate dual pass systems, one loop of which was used for ground cooling purposes, the other for the closed flight system.

The AM ground cooling system configuration used at the VAB and pad, as illustrated by Figures 2.15-19 and -20, was located on the Mobile Launcher 280-foot level, with a redundant backup system on the 300-foot level. This system provided the capability to handle a generated heat load of 16,000 Btu/hr by delivering MMS-602 coolant fluid to the FAS umbilical interface at a temperature of -15°F and at a flowrate of 900 lbs/hr.

The AM ground cooling and coolant loop servicing system used at the MSOB on the Integrated Test Stand (ITS), Level 2 and the configuration used at St. Louis were essentially the same and differed from the system used at the VAB and pad in that the GSE units were not designed for operation in a hydrogen atmosphere nor for remote operation. Functionally, the MSOB and St. Louis systems were identical to the pad system.

The ground cooling systems consisted of the GSE end items listed below:

52E180004	Cooling and Servicing Unit
52E180172	Refrigeration Unit - Auxiliary
58E181217	Remote Control Panel
52E180183	Coolant System Pressurization Unit
52E180184	Coolant Fluid Transfer Kit
52E420172	MMS-602 Coolant Fluid Filter Cart
52E180022	Coolant and Solvent Shipping Container
GCE18-066	Syringe Kit
52E180005	Coolant System Drying Cold Trap

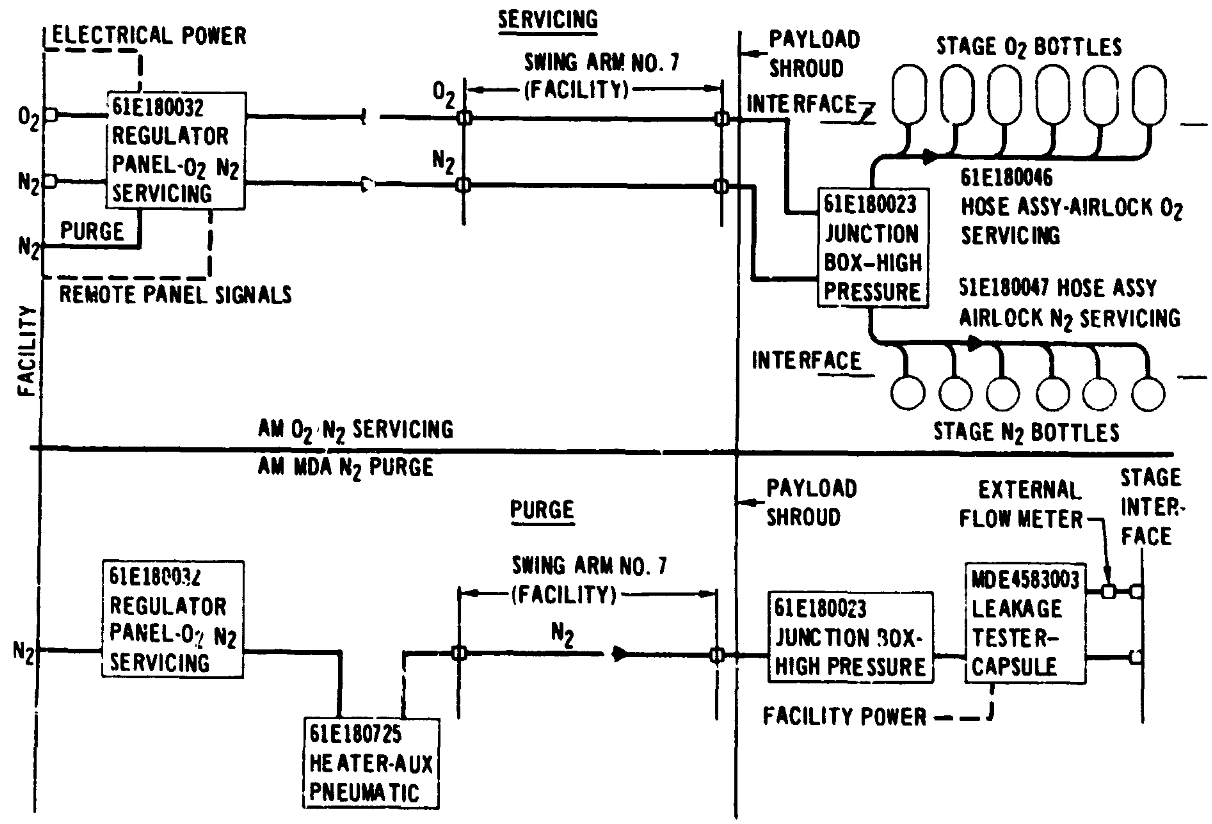


FIGURE 2.15-18 O_2/N_2 SERVICING AND AM/MDA N_2 PURGE SCHEMATIC

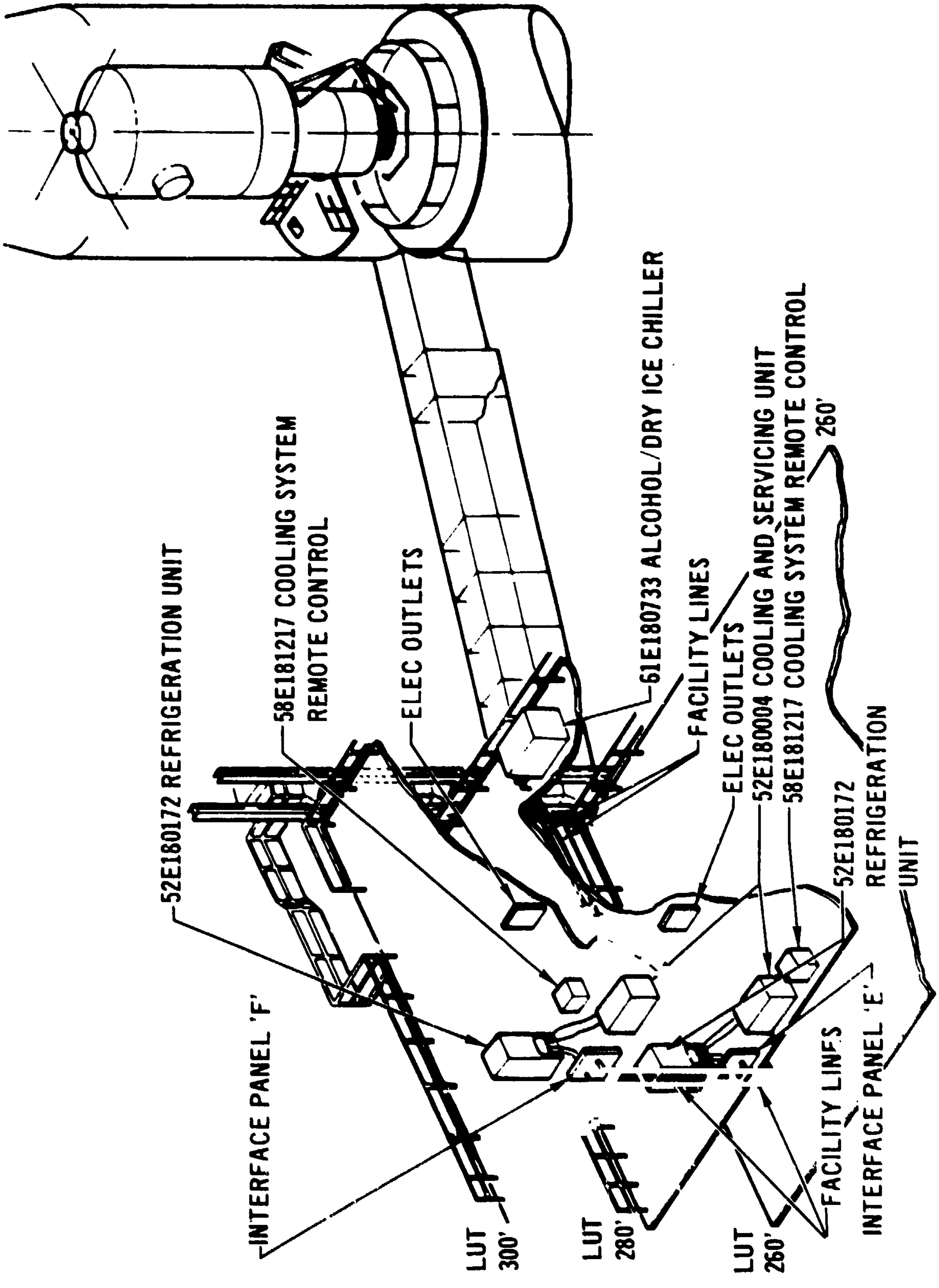


FIGURE 2.15-19 AIRLOCK GROUND COOLING

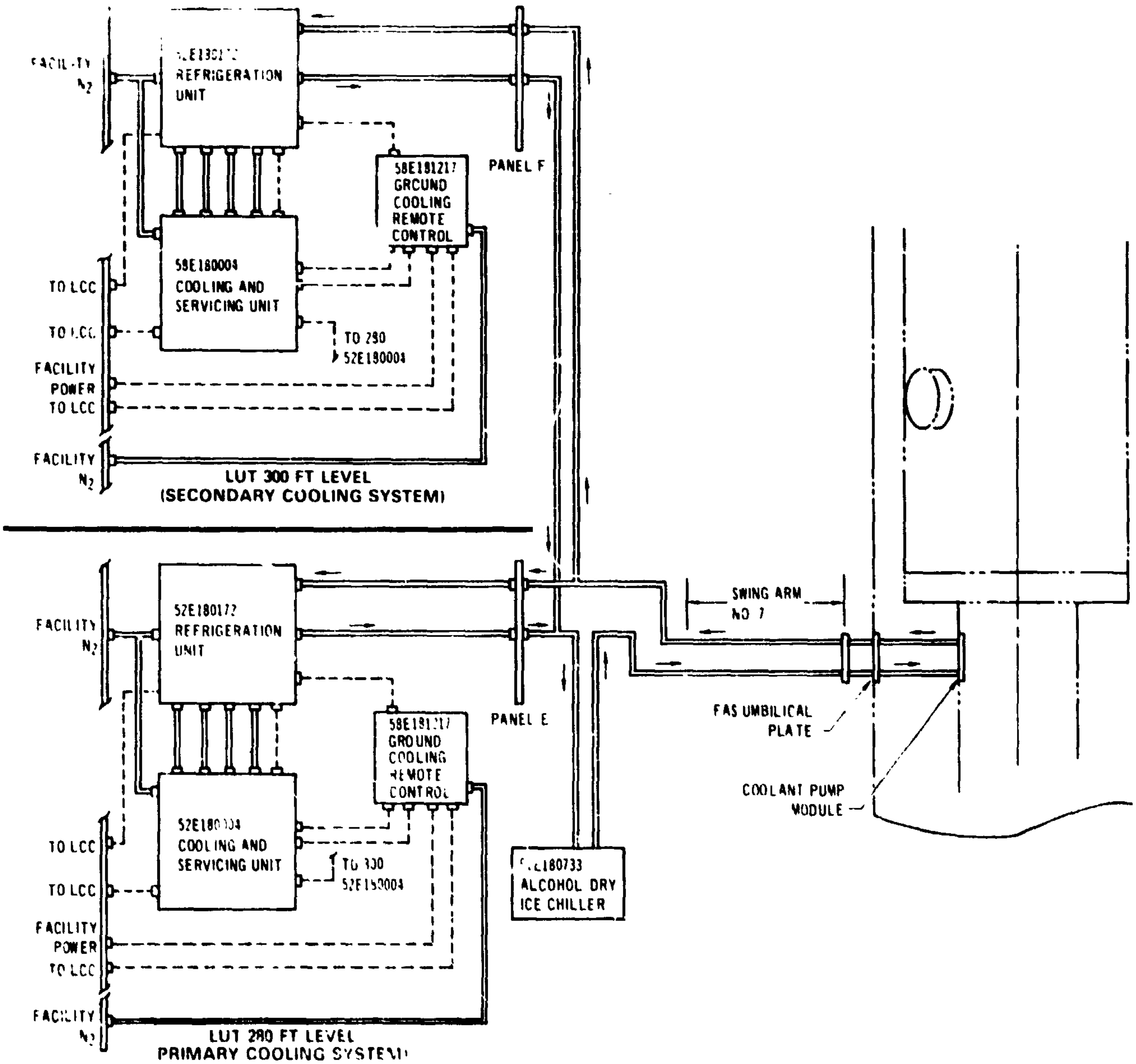


FIGURE 2.15-20 AIRLOCK GROUND COOLING SCHEMATIC

61E180733 Alcohol/Dry Ice Chiller
52E180160 Coolant System Flush and Purge Unit
Various Hose Assemblies

This complement of GSE also provided the capability to service, deservice, flush, purge, and dry either the flight cooling or ground cooling loops.

(3) AM Water Servicing System - The AM water servicing system was used at KSC during prelaunch testing and servicing to transfer approximately 50 pounds of high purity water, conforming to Specification MMS-606, from external reservoirs to the flight vehicle water tanks. Two flight tanks were serviced for the personnel pressure suit cooling system (SUS) and one tank for the Apollo Telescope Mount (ATM) C&D/EREP cooling system. The AM water servicing systems consisted of the following GSE end items:

61E180720 Suit Coolant System Polishing Kit
52E180005 Cold Trap Assembly
52D180672 Water Supply Storage Containers
61E180042 Manifold Assembly
52E180194 Leak Rate Tester
GCE18-047 Portable Vacuum Pump Assembly
61N180052 ATM Deservicing Kit
61E180726 O_2 Analyzer Kit
61E180707 Suit Simulator
61E180043 Vacuum Gauge

(4) Altitude Chamber Fire Suppression System - MDAC-E GSE Engineering designed a high-expansion foam fire suppression system for use in the AM/MDA during unmanned altitude chamber runs. All known fire suppressant materials were evaluated for compatibility with the 5 psig oxygen-rich environment present in the flight vehicle during altitude chamber tests, resulting in the selection of foam as the most suitable suppression agent for an assumed "worst" case situation involving a Coolanol 15 spill.

A schematic of the foam system is shown in Figure 2.15-21. An aqueous premixed emulsion containing 3.6% (max.) by weight of hydrolyzed protein was fed under pressure to the generator station,

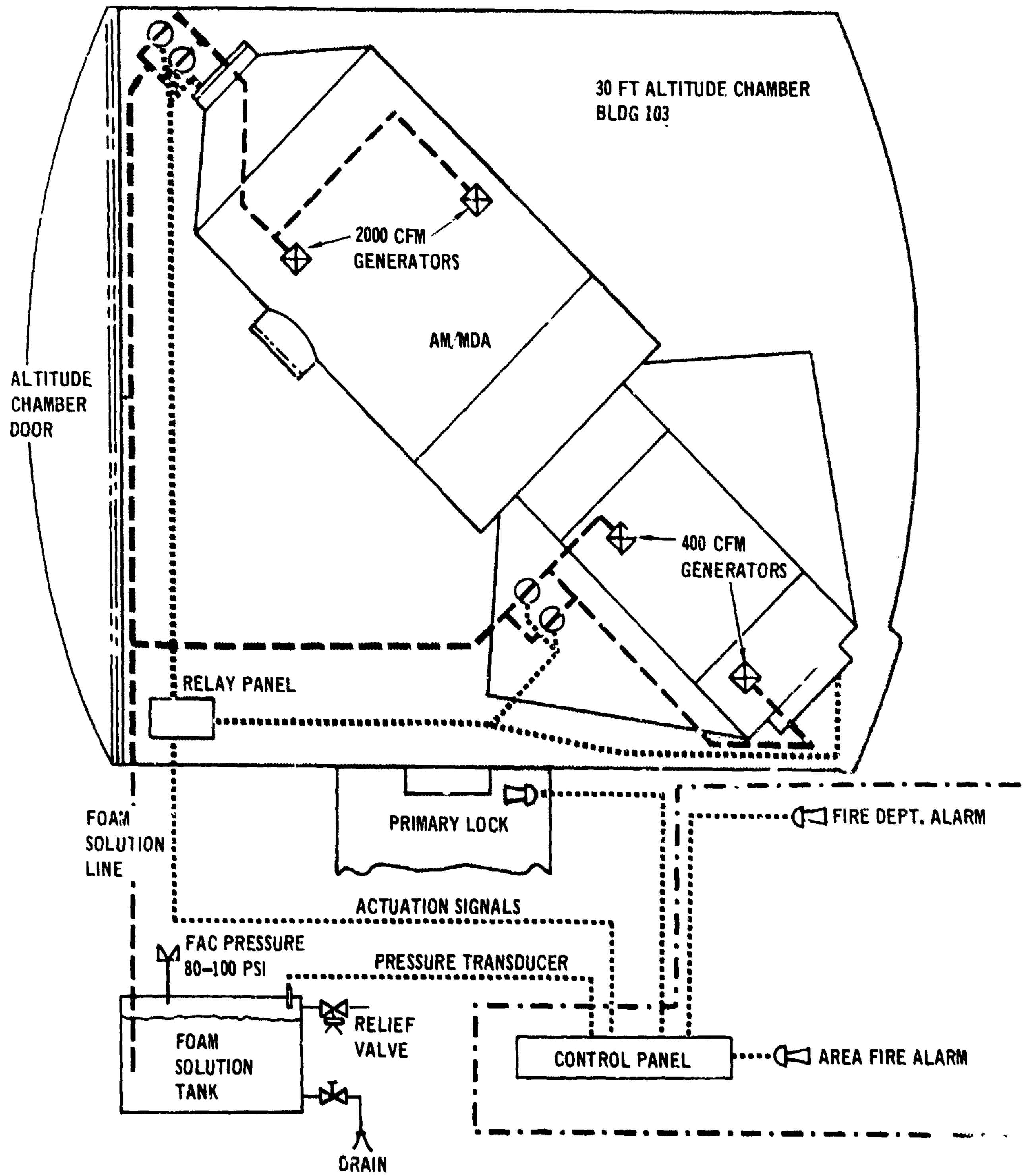


FIGURE 2.15-21 ALTITUDE CHAMBER FIRE SUPPRESSION SYSTEM

where the liquid was passed through a hydraulic fan motor, expanded in a 600-800:1 ratio, and dispersed by fan action. The four generators shown in this figure could fill the interior volume of the AM/MDA in 30 seconds.

2.15.4 GSE Certification

Certain newly designed GSE items experienced problems during the trial fit of mechanical GSE items and production acceptance tests on operational fluids and electrical GSE items. A complete history of these discrepancies and anomalies is contained in program records, which is too lengthy to repeat in this report. All such discrepancies were resolved prior to NASA acceptance of the items, and all GSE items were placed in service in time to perform scheduled functions.

2.15.4.1 Mechanical GSE Certification Criteria

The MDAC-E design for lifting, hoisting, and handling equipment items were certified as follows:

A. Strength Analysis - A detailed strength analysis was performed on the critical components of each item during the design phase. All loading cases and loading directions were determined. The worst case loading condition governed design.

B. Proof Load Diagram - The design drawing for each mechanical item, which required a production proof load test, included a sketch of the item showing the magnitude and direction of the worst case imposed working and proof loads.

C. Strength Engineer Approval - Each Mechanical GSE Assembly and detail design drawing required the approval signature of a GSE Strength Engineer prior to release, regardless of whether the particular items required proof testing.

D. Trial Fit/Installation Checks - A trial fit and installation check was accomplished on those mechanical GSE items which had a functional interface with flight hardware. Trial fit checks were scheduled so as to allow sufficient time to resolve discrepancies prior to first required usage of the item.

E. Production Acceptance Test - All GSE end items designed to perform a lifting or hoisting function were subjected to a proof load test value not less than twice the rated working load capacity of the item. Any evidence of permanent deformation or yielding was cause for rejection. A proof load certification placard which indicated the proof load value test, and inspection seal was affixed to each proof tested item.

F. Periodic Recertification Tests - Each GSE item requiring a proof test was subjected to periodic recertification tests equal to the original proof load test. The frequency of recertification testing was dictated by item usage or was performed on an annual basis.

2.15.4.2 Electrical/Electronic GSE Certification Criteria

The contractors designs for electrical/electronic checkout and test GSE end items or systems were certified by the following means:

A. Systems, Network, and Circuit Analysis - The overall system block diagram and system schematic were verified for compliance with the applicable design criteria.

B. Systems Safety Analysis - Each design configuration was reviewed for compliance with applicable portions of the Airlock Safety Plans, Government Specifications, etc., prior to release of the drawing to manufacturing. The adequacy of this pre-release review was demonstrated by the fact that an independent systems safety checklist analysis of all GSE conducted between September 1971 and April 1973 revealed that only two potential problems, which were subsequently corrected, existed in the total complement of electrical end items.

C. Interface Compatibility Reviews - GSE to facility, GSE to GSE, and GSE to flight hardware interface cabling and connectors were reviewed throughout the program to ensure equipment utilization compatibility at the using facilities. As a result of this effort, there were no instances of interface incompatibility at MDAC-E.

D. Production Acceptance Test - All newly designed electrical GSE end items were subjected to functional performance as specified in the D5-11 series SEDR documentation. Electrical GFE items from other programs were

recertified either per the acceptance test procedure utilized on the prior programs or by an abbreviated readiness test procedure.

E. Periodic Maintenance and Recalibration Checks - Electrical GSE end items and components were maintained in good working condition by a detailed, computer tabulated periodic maintenance program which assured precision of all data displays and test results.

F. Functional Requirements - Flight vehicle systems verification tests and test parameters were defined and documented in MDC Report E0122, "Test and Checkout Requirements, Specifications, and Criteria at KSC for AM/MDA." Requirements for contractor in-house systems tests and component/module pre-installation acceptance tests were coordinated within Project, ATLO, and GSE disciplines.

Functional test requirements were analyzed, and descriptions of the GSE end items or systems were written to implement the defined tests. These test requirements and associated GSE item descriptions were then documented. NASA subsequently approved each test definition/requirement and the functional GSE necessary for test implementation.

2.15.4.3 Fluids GSE Certification Criteria

MDAC-E designs and system configurations for fluids GSE end items were certified as follows:

A. End Item and System Schematic Analysis - The block diagrams and system schematics for each end item were prepared and analyzed by the responsible GSE fluids engineer in compliance with flight vehicle constraints and functional performance criteria. Mathematical analysis data concerning such parameters as flowrates, pressure and temperature profiles were completed and documented prior to the initiation of design.

B. Systems Safety Analysis - Each design configuration was reviewed for compliance with the Airlock Safety Plan, Government Specifications, etc. prior to release of the drawing to Manufacturing. Particular emphasis was placed upon fail-safe GSE designs, so that a failure in the GSE system would not cause a related failure in the flight systems. Potential

operator errors were minimized by graphically displaying the flow schematics on control panels. System Safety Checklists were prepared for each hazardous and mission essential GSE which were reviewed by Project Safety and then submitted to NASA. In addition, specific operating instructions were prepared for each major end item (Operation and Service Manuals - D5 Series SEDR).

C. Proof Pressure Tests - Each end item was subjected to operational proof pressure tests at twice the maximum working pressure of the unit or system, and these tests were repeated at intervals as specified in contractor periodic maint[illegible] records. The end items were designed to withstand a burst pressure equal to four times working pressure.

D. Production Acceptance Tests - Major fluids GSE end items were subjected to acceptance tests which verified their functional performance characteristics. These test procedures were specified in the D5-11 series SEDR documents. In addition, an operational readiness test was conducted on complex end items prior to use in a systems context.

E. Periodic Maintenance and Recalibration Checks - As with electrical GSE, fluids GSE end items were maintained in good working order by a detailed, computer tabulated periodic maintenance program. Gages, flowmeters, and other set point type devices were calibrated every six months to assure the accuracy of data displays and test results.

F. Functional Requirements - Flight vehicle fluid systems verification and test parameters were defined and documented in MDC Report E0122, "Test and Checkout Requirements, Specifications, and Criteria at KSC for AM/MDA." Requirements for vehicle systems test and component/module pre-installation acceptance tests conducted at MDAC-E were coordinated between Project, ATLO, and GSE disciplines.

Functional test requirements were analyzed and descriptions of the GSE end items or systems were written to implement the defined tests. These test requirements and associated GSE item descriptions were then documented. NASA subsequently approved each test definition or requirement and the functional GSE necessary for test implementation.

2.15.5 Conclusions and Recommendations

The MDAC provided GSE used in support of the AM, FAS, DA, and PS performed its intended functions during all phases of program operations. Various problems were encountered in the qualification and verification of several GSE end items and systems, but all were resolved without causing program delays.

2.15.5.1 Mechanical GSE

All mechanical GSE end items performed their intended functions. The various manufacturing and operational problems proved to be readily solvable. The minimum required complement of GSE end items were manufactured on schedule and within target costs. In many cases, GSE end items were designed to accomplish multiple functions, as illustrated in Figure 2.15-11, thus reducing the total required mechanical GSE complement.

Limited use was made of available mechanical GFE from other programs as indicated by the summary provided in Paragraph 2.15.3.1 (A). For example, MDAC-E utilized the Apollo SLA transporter and the LM Adapter Base to transport the mated AM/MDA/FAS/PS cylindrical section at KSC between the MSOB and VAB in lieu of designing a new transporter. Most mechanical GSE designs are intended to accomplish specific functions with interfaces peculiar to a given flight article. This high degree of design uniqueness limits the application of mechanical GSE between programs. However, several Airlock GSE mechanical items are considered to have potential application on other aerospace programs. The AM/MDA horizontal trailer, for example, (Ref. Figure 2.15-7) could be adapted to handle other large payloads. Therefore, it is recommended that NASA review the Airlock GSE Closeout Status Report to prevent the scrappage of potentially reusable hardware.

2.15.5.2 Electrical/Electronic GSE

The AM electrical/electronic GSE end items and systems configurations successfully performed the required test, checkout, and monitor functions. A considerable cost savings in both design man-hours and hardware was realized on the Skylab Program through effective utilization of residual GFE from NASA Gemini and Gemini B Programs. Approximately 55% of the Airlock electrical GSE requirements were satisfied through the use of these existing GFE inventories. This effective

utilization of GFE was possible because the same systems engineers who originally designed the equipment on prior programs were available to integrate its known capability into Skylab GSE systems. Had this been GFE from another program, such as Apollo, the same degree of successful conversion probably would not have been attainable. However, most of this older GFE is no longer recommended for use on future programs due to the number of operational hours on the equipment and the now obsolete status of the commercial component configurations.

Where specific GSE end items or components thereof were considered to have possible application on future programs, MDAC-E recommended that such hardware be retained on the MDAC-E Facility Contract or for NASA transfer to other users. Detailed disposition recommendations are contained in the "Airlock GSE Closeout Status Report."

2.15.5.3 Servicing and Fluids GSE

The AM fluids GSE end items and systems, configured for compatibility with the flight vehicle systems/components to be tested, serviced, or otherwise supported, performed their intended functions.

As with the electrical GSE, a considerable cost savings was also realized in the fluids GSE area by utilizing residual GFE from the NASA Gemini and Gemini B Programs. In this case, approximately 53% of the Airlock fluids GSE requirements were satisfied through the use of these existing GFE inventories.

Again, however, the fact that the same fluids GSE systems engineers who originally designed the GFE were available to determine applicability on another program contributed materially to successful GFE utilization. Even with this detailed GFE background knowledge available, adaptation problems occurred. One such design problem occurred in adapting residual cooling system GFE from the NASA Gemini Program to meet AM Ground Cooling System operating requirements at KSC during test and prelaunch activities. Ultimately, this situation was resolved by modifying two 52E180004 Cooling Units to handle higher Coolanol pumping pressures at lower delivery temperatures, redesigning two 52E180172 Refrigeration Units to satisfy reduced temperature and increased heat load requirements, and adding a supplemental alcohol-dry ice chiller, 61E180733. This is one case where it would, in retrospect,

have been better to start with a new design initially.

Generally, the standard and vendor components utilized in the design of manually controlled fluids GSE are less subject to wearout and/or obsolesence due to technology/state-of-the-art advances than their electrical GSE counterparts.

In addition, many types of fluids GSE items, such as leak rate testers, mobile high pressure supply carts, regulation panels, test benches, etc. were configured as multi-use/multipurpose devices and could be considered as available GFE for use on future programs. MDAC-E recommendations for disposition of these items are contained in the "Airlock GSE Closeout Status Report."

2.15.5.4 GSE Documentation

Skylab Program GSE documentation was held to a minimum with no loss of management visibility and control or schedule slippage. In-house paperwork was supplemented by a small group of GSE Engineers who performed direct liaison functions with the manufacturing departments. This direct man-to-man relationship provided swift resolution of both engineering and manufacturing problems and bottlenecks, allowed the close tracking of parts and progress to assure on-time delivery, and effected tight, coordinated control over equipment changes without impacting KSC operations.

Computerized data programs inputed by engineering, planning, and manufacturing assisted in maintaining and updating production schedules, test schedules, shipping schedules, and parts traceability.

MDAC-E found that a program characterized by a minimum of NASA imposed documentation coupled with flexible contractor in-house control procedures produced significant program cost savings and contributed materially to meeting required schedules.

2.16 SYSTEMS SUPPORT ACTIVITIES

Several support activities were applicable to all systems. These included the electromagnetic compatibility study, the sneak circuit analysis, the maintenance study, and the extensive spares support effort.

2.16.1 Electromagnetic Compatibility Requirements

2.16.1.1 The EMC Design

Requirements for the AM were detailed in the AM EMC Control Plans, MDC Reports E853 and H031. The requirements were categorized for both equipment design and total module design. The implicit requirement in both control plans was that the AM be compatible with itself and with other modules of the cluster.

A. Component - Report E853 applied to equipment designed before 2 May 1970, providing guidelines to the design of this equipment and required tests per MIL-I-26600 or equivalent. Report H031 provided design guides and required equipment designed after 2 May 1972 to be tested to and comply with MIL-I-6181D.

B. Module - Report H031 required that module compatibility be demonstrated in compliance with MIL-E-6051C and that the electrical bonding of the module meet the installation requirements of MIL-B-5087B. Other module level requirements of Report H031 included:
   - Demonstration of 6 dB safety margin on critical circuits.
   - Exposure of vehicle to radiated power levels 6 dB above the expected mission levels.
   - Measurement of radiated interference in the passbands of cluster receivers.
   - Resistance measurements of representative bonds and of the vehicle, end-to-end.

2.16.1.2 EMC Integration -

MDAC-E performed EMC Integration functions to ensure a compatible Skylab vehicle. These activities included the following:

- Review of and recommendations on all module EMC Control Plans and Interface Control Documents to achieve design compatibility.
- Performance of analyses to establish module and cluster interface EMC test points and their compliance criteria.
- Support of the Skylab EMC Board.
- EMC testing and analysis as required by MSFC.

2.16.1.3 System EMC Philosophy and Tradeoffs

A. Grounding - The approach taken on system grounding can cause very serious impact on equipment and system design and on the costs involved with EMC problem resolution. The choice in system grounding between single point vs. multiple point grounding involved a tradeoff judgement based on the following factors:

Factors	Single Point	Multiple Point
Control of return current routing	Controlled by wire routing	Uncontrolled
Low impedance	Can be high Z to RF noise	Low if structure bonding resistance is low
Flexibility in resolving EMC system problems	Wire routing can be changed, ground point to structure can be changed or additional grounds added. Low impact	May require equipment redesigns. High impact on cost and schedule

The decision on Airlock was to utilize a single point ground to provide control of return current routing and provide design flexibility in case grounding system changes were necessary. Provisions were made for removing this structure connection from the Airlock and making it through the CSM. RF grounds on transmitters and receivers were of necessity referenced to structure. Signal returns were run separately from power returns to the single point ground so that power system noise did not appear on signal circuits due to common (shared) impedances. There were no exceptions to the single point ground requirement in the Airlock design and as a result there were no structure currents in Skylab contributed by Airlock equipment.

B. Isolation - Power, signal (except for RF grounds), and case grounds were isolated from each other within the equipment and throughout the system interconnect wiring. These grounds became common only at the single point ground, thus precluding ground loops and common impedances.

C. Electrical Bonding

(1) Equipment Cases - Equipments which generated, or were susceptible to RF interference were electrically connected to vehicle structure through a low impedance (2.5 milliohms or less) connection. This

technique prohibited the development of high RF potentials. RF bonding was accomplished either by metal-to-metal contact of equipment case to structure or by use of bond straps.

(2) Static and Safety - All other electrical/electronic equipment cases were connected to structure via a wire for protection against static charge build-up and to provide return for fault currents. All such Airlock static grounds were sufficient to prevent static charging. A static discharge problem was discovered during nitrogen purging operations of the ATM C&D water tanks. Arcing was observed between an isolated conductive support ring and the vehicle structure. It was determined that the support rings were collecting a static charge from friction of the nitrogen flow or the internal rubber bladder rubbing against the plastic walls of the case. This problem was solved by installing grounding wires between the conductive members of the water tank assemblies and structure.

All Airlock primary structural members had low impedance (2.5 milliohms or less) electrical connections at structural joints and interfaces. This resulted in an equipotential ground plane, provided lightning protection, and prevented the development of RF potentials between members. It also provided minimum DC voltage drop in the power system for those equipments in modules other than Airlock, which require their power circuit return through structure.

D. Shielding - Signal circuits with frequency content below 50 KHz and which could be susceptible or an interference source were shielded with the shield grounded to structure at one point only. Signal circuitry with frequency content above 50 KHz and which could be susceptible or an interference source were shielded with the shield grounded to structure at both ends and at as many other points as practical. Shields were not used to carry signals except in the case of coaxial cable. Power circuits were not shielded.

E. Critical Circuit Safety Margins - The tradeoff involved in deciding whether to require critical circuit safety margins is the dollar cost and schedule versus an unknown risk to astronaut safety or to mission success. The decision on Airlock was to expend the effort necessary

to demonstrate critical circuit safety margins and therefore to increase confidence in a safe and successful mission. On Airlock, a critical circuit was defined as a circuit, which if susceptible to interference, could cause a system response that would directly affect crew safety, or that would cause mission abort or failure to achieve a primary mission objective. After the critical circuits were identified they were subjected to EMC tests to determine the conducted susceptibility threshold. This is the level of noise voltage which causes a critical malfunction. During vehicle level simulated flight testing, noise voltage measurements were made on the critical circuits. The noise levels were then compared to the susceptibility threshold levels to obtain the margin of safety. Typically, a safety margin of 6 dB was required. Experience had proven that this is an acceptable margin and it was the margin used for Airlock requirements.

F. Radiated Susceptibility Safety Margin - The Skylab cluster contained several RF transmitters. Since the radiated power densities impinging or Airlock equipment were known to exceed the equipment qualification levels, it was deemed advisable to subject the vehicle to power densities 6 dB above those expected during the missions. By subjecting the vehicle to all the transmitter frequencies simultaneously, susceptibility to the intended frequencies could be obtained, as well as the effects of any mixing.

G. Cluster Passband Interference - In order to assure that the Skylab receivers would not be degraded by radiated interference emanating from Airlock equipment, interference measurements were required in the passbands of Cluster Receivers.

2.16.1.4 Test Program

Compliance with the EMC requirements was demonstrated by test at the component level, module level and the module to module level. The EMC test flow is shown in Figure 2.16-1.

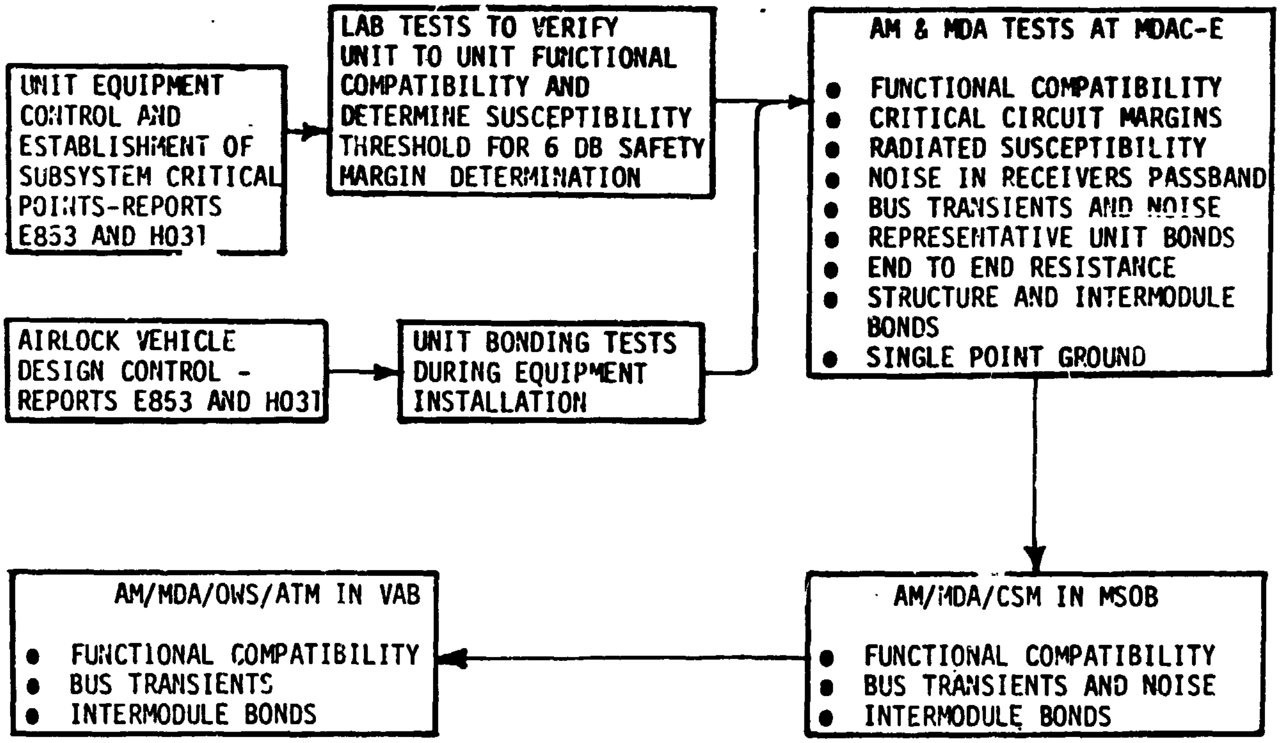


FIGURE 2.16-1 ELECTROMAGNETIC COMPATIBILITY TEST FLOW

A. Component - Compliance with the equipment requirements was demonstrated by qualification tests. All AM electrical/electronic equipment was tested per the appropriate test requirement. Deviations were submitted, justified and approved for all out of specification conditions. These conditions were minor in nature and caused no problem in system tests or mission performance.

B. Module - Compliance with the electrical bonding requirements was demonstrated in the AM Systems Validation Test. Compliance with vehicle level EMC test requirements was demonstrated by two vehicle tests. The all systems part of Systems Assurance Test and the

Simulated Flight Test, demonstrated that all Airlock systems operated together compatibly. During the Simulated Flight Test the required 6 dB margin between the noise on critical circuits and the susceptibility of the circuits was demonstrated except during two transient conditions. These two transients occurred on circuits between the DCS and CRDU. It was determined that one of the transients was caused by facility equipment external to the vehicle and the other was caused by the crew operating the Light Dimmer Control out of the proper sequence. Neither of these were above the operating level of the circuits. A Deviations Approval Request was approved on these conditions. It should be noted that, although physical constraints precluded including the ATM Deployment Assembly in the test setup, the electrical/electronic equipment which was normally mounted on the DA was connected to the Airlock and operated in proper sequence during the Simulated Flight Tests. Other EMC requirements fulfilled during Simulated Flight were radiated susceptibility and receiver passband noise measurements. The Rapid ΔP Sensor was found to be susceptible to VHF radiation and as a result, the sensor was modified and a special filter cable was incorporated in the vehicle wiring. Noise measurements in the receiver passbands revealed no measurable interference.

C. Module To Module - During the Simulated Flight Test the AM was operated successfully with the MDA. It became necessary to perform this test twice, due to late delivery of certain MDA equipment. In addition, tests were performed at KSC which demonstrated that the AM operated compatibly with the other modules of the Skylab Cluster. EMC tests performed in the MSOB and VAB included transient voltage measurements at the bus interfaces and bus ripple noise measurements. The results of these measurements indicated that no EMI problems existed at the bus interfaces.

2.16.1.5 Mission Results

No EMI problems were identified on Airlock during manned or unmanned phases of the Skylab mission; two transistory timing problems were suspected to have been caused by EMI. However, MSFC requested that EMC tests be performed on the backup AM/MDA vehcile as a result of a failure during the mission of the attitude control rate gyros on the Apollo Telescope Mount. These tests consisted of impedance and noise measurements.

A. Impedance Measurements - This test was performed to determine the impedance of the AM power bus at the AM/ATM interface. Vehicle configurations simulated that which existed during the first few days after launch of SL-1. The frequency range covered was 1 KHz to 200 KHz. Maximum impedance was approximately 12 ohms at 200 KHz. The purpose of this test was to enable MSFC to better simulate and analyze the conditions present when the rate gyro failures occurred.

B. Noise Measurements - A rate gyro "six pack" was taken up and installed by the second Skylab crew. In support of this operation, noise measurements were made at the utility outlets of the backup MDA. Results indicated that noise levels in the susceptible frequency range of the rate gyros were well below the malfunction threshold and therefore the "six pack" should not be affected by AM Bus noise. This conclusion was born-out when the package was installed by the crew and operated normally.

2.16.1.6 Conclusions and Recommendations

The Airlock Systems operated successfully through three manned missions and four unmanned periods with no demonstrated EMI problems. Airlock systems were unaffected by interference from other modules and did not interfere with the operations of other modules. This successful mission performance verifies the adequacy of the EMC design philosophy and test program.

Since the primary objective of EMC testing is to demonstrate functional compatibility of the electrical/electronic systems with one another, it is important that the total system be operated in as many configuration combinations as possible. Vehicles of the complexity of Airlock presented two problems in this respect. The number of configuration combinations was so large that it became totally impractical to test all combinations by manually controlling the systems. The other problem was that manual evaluation of the resulting test data was a formidable task because of the huge quantity of data, and that the results were significantly subject to human error. These difficulties could be largely alleviated and the general test effort made more cost effective by implementing automation techniques in the test operation and utilizing data compression and computer evaluation of the massive test data.

It is recommended that future programs of the complexity of Airlock utilize these techniques to insure a thorough test and evaluation in a relatively short test cycle.

It is believed that, if automated testing and data compression techniques are included in the early program planning, test time and resultant costs will be significantly reduced.

2.16.2 Sneak Circuit Analysis

MDAC-E supported the performance of a complete Sneak Circuit Analysis on all electrical and electronic circuits and components contained in the Skylab vehicle. This analysis included primary power and control circuits, switched secondary power and control circuits, switched signal circuits, command circuits, module interface circuits, and those ESE circuits assoicated with final countdown and launch.

The objective of the Sneak Circuit Analysis was to identify any circuit configuration or operation which could cause an undesired function to occur or a desired function to be inhibited.

2.16.2.1 Program Support

The basic MDAC-E involvement in the Sneak Circuit Analysis effort consisted of the submittal and interpretation of Airlock module data and operational documentation and the assessment of all items of concern generated by program analysts. To accomplish these tasks, St. Louis and MSFC on-site resident teams were established and maintained for the duration of the program.

Internal electrical design information was provided for approximately 155 Airlock system components ("black boxes") and external electrical design data was furnished for the entire Airlock Module. This required the initial submittal of 746 separate drawings and, to reflect configuration changes, the later submittal of 240 drawing revisions and 700 EO's.

To aid the analysis effort, 24 data cross-reference lists were generated and maintained by MDAC-E. These lists contained such information as equipment part number vs. wire bundle numbers, part numbers vs. production drawing zones, top assembly numbers vs. detailed drawings, etc.

MDAC-E personnel at MSFC participated in activities of the MSFC Sneak Circuit Review Board which had the responsibility for categorization and ultimate resolution of all potential problems identified during the review. They also worked closely with the analysts to aid in data interpretation, to provide system operational information, and to forestall the issuance of erroneous problem reports due to lack of system understanding. MDAC-E St. Louis and on-site

personnel responded to all system items of concern, including the Airlock. Some items required extensive analysis and study before a resolution could be recommended but most could be answered by a brief explanation of system operation and design background. In at least two cases, arrangements were made for meetings with vendor design personnel who provided detailed information on specific black box design and operational functions.

2.16.2.2 Results

During the analysis, if a discrepancy was found in the system data (drawings) or documentation, a Drawing Error Report (DER) was generated. System functional or design discrepancies resulted in the issuance of one or more of the following:

- Sneak Circuit Bulletin - Circuit had subtle characteristics which could constitute a latent threat.
- Problem Report - Circuit design could result in component overstress or malfunction.
- Design Concern Report - Circuit had features which could be undesirable.

The total review program resulted in the following assessment of Airlock system circuits

- Drawing Error Reports 16
- Sneak Circuit Bulletins 3
- Problem Reports 5
- Design Concern Reports 23

A. Drawing Error Reports - All drawing errors identified were minor part number and/or nomenclature discrepancies. No hardware was incorrectly wired or assembled. Drawings were corrected by later revision except for vendor prints where the vendor was no longer under contract.

B. Sneak Curcuit Bulletins - The following potential problems were investigated:

(1) Relay Timing Race - When payload shroud deployment circuits were activated, one set of relay contacts was opened to disconnect a circuit ground while another set of contacts on the same relay were closed to apply power. If any overlays occurred between the two events, a power-to-ground short could exist momentarily. Relay tolerances, specifications, and standard tests effectively precluded this type of discrepancy and the condition was considered extremely

improbable. NASA recommended no hardware change and no further action.

(2) Simultaneous Relay Activation - If manual and DCS "Crew Alert" reset commands were issued simultaneously, the CRDU output would be connected momentarily to EPS Control Bus No. 1 through the contacts of the "master alarm status lights" relay. This condition was not likely to occur and would not have been detrimental to the system if it had occurred momentarily. NASA recommended no further action.

(3) Ambiguous Control Labels - The molecular sieve fan disconnect switches did not directly remove power from the fans but only switched the operating function from "automatic" to "off." A caution note was added to the operational procedures to clarify this item.

C. Problem Reports - All reports except one were closed without further action. A document change was initiated to close this one report.

D. Design Concern Reports - Three reports were closed by requests for nomenclature changes. All others were closed without further action. The reports were concerned with minor circuit idiosyncrasies, extra components, current monitoring, etc. and were not considered to be detrimental to system operation.

2.16.2.3 Mission Results

No mission problems were attributed to sneak circuits.

2.16.2.4 Conclusions and Recommendations

Sneak circuit analysis verified the adequacy of the AM circuitry design and gave added assurance that critical functions would occur only as planned. Mission operation verified no problem due to sneak circuits. It is recommended that a sneak circuit analysis be implemented early in the design phase of all future space vehicles.

2.16.3 Maintenance Technology Support

Maintenance Technology provided close coordination to assure the necessary maintenance requirements and scheduling to meet test and shipping schedules. This effort involved 2000 pieces of GSE and 700 pieces of AVE. The GSE requirements required scheduling of 12,600 line items to assure maintenance was performed on schedule to support test and preparation for shipment schedules.

Several reports were generated for preflight, inflight, and postflight AVE maintenance. Maintenance data was also provided for GSE and storage of both AVE and GSE.

2.16.3.1 Preflight AVE Maintenance

Airlock Systems Maintenance Summary, MDC Report PS 315, presented a summary of preventive maintenance for flight equipment (AVE) including:

- Preventive and corrective maintenance requirements.
- Age control and life limit data.
- Storage requirements.
- Maintenance provisioning levels.
- Retest requirements and location.
- Accessibility for maintenance and maintenance test point listings.
- Shelf and installed life.
- Calibration Frequency.
- Critical Life.

2.16.3.2 Inflight AVE Maintenance

An Airlock Inflight Maintenance (IFM) MDC PS Report E501-11, provided a summary of IFM candidates and the support requirements. This document established integrated IFM and support requirements for the overall cluster and provided supporting data and candidate selection rationale to permit establishment of the following:

- Consolidated tool and spares requirements.
- Planning for crew training, spares, and equipment stowage.
- Maintenance procedure requirements.
- Candidate coordination, trade off and approval by NASA.

Figure 2.16-2 lists tools and inflight AVE spares that were recommended and approved for the Airlock Module.

- SL-1/SL-2 Tools

5/32" Square Allen Bit	
Spin Handle	
3/16" Blade Driver	
3/8" Blade Driver	
7/16" Deep Well Socket	
4" Extension	
Ratchet Handle	
Connector Pliers	
3/32" Blade Driver	
9/16" Wrench	
3/8" Socket	
Hi-Torque Driver Bit 3	
8" Extension	
Knife	
Pinch Bar	
Hose Assembly (60')	61A830355-13
Jumper Hose Assembly	61A830356-9
Deservicing Adapter	61A830357-7
Hose Assembly	61A830401-1
Deionizer Assembly - Water	61V830080-1
Adapter Assembly	61A830387-1, -2
Hose Assembly	61A830388-1
Condensate Tank Module	61A830045-33

- SL-1/SL-2 Stowed Inflight Maintenance Spares

CO_2 Active Filter Cartridge (Inlet)	52-88715-115 (20)
CO_2 Passive Filter Cartridge (Inlet)	52-88715-95 (20)
CO_2 Active Filter Cartridge (Outlet)	52-88715-121 (12)
CO_2 Passive Filter Cartridge (Outlet)	52-88715-99 (12)
Crewman Communication Umbilical	61A762216-305 (1)
SPKR Intercom Assembly	61A830003-321 (1 in MDA)
AM Tape Recorder	61A800018-5 (4)
PLV Fans (GFE)	20M42270-3 (3)
O_2 Sensor	61B880055-23 (6)
Mol Sieve Fan	61A830017-11 (1)
Solids Trap	61A830190-11 (28)
20-Watt Bulb	61V762350-3 (24)
Mol Sieve Charcoal Canister	61B830010-87 (8)
Portable Timer Battery	61B880051-5 (4)
H_2O Filter (ATM C&D)	61A830219-17 (2) & 61A830219-19 (4)
Fire Sensor	61A830301-25 (2)
H_2O Separator Plate Assembly	52-83700-1219 (4)
EVA/IVA Coolant Gas Separator (GFE)	SEC 11100080-302 (2)
Lt. Wt. Crewman's Umbilical	61A762308-301 (2)
Teleprinter Paper Cartridge	61B850018-17 (1)
TV Input Station (GFE)	82000003800-020 (Spare in MDA)
Fire Sensor Control Panel	61A800026-11 (1)
Teleprinter Spools	61B850018-13 (2)
Control Head	61A762309-305 (1)
Tone Generator Battery	61B880051-9 (12 Flight - 24 Backup)
Condensate Tank	61A830045-33 (1)
CO_2 Detector End Plate (Inlet)	52-88715-105 (1)
CO_2 Detector End Plate (Outlet)	52-88715-107 (1)
Clock	61B850021-5 (1)
Fire Sensor Indicator Lamp Assembly	52-79718-73 (3)
10-Watt Bulb	61V762350-1 (120)
ATM Film Transfer Boom and Hook	
Boom	61V820001-1 (1)
Hook	61A820137-1 (1)

- Additional MDAC-E Supplied IFM Spares for SL-3

Tape Recorders	61A800317 (2)
New $PPCO_2$ Cartridge for Test	61V830072 (1)
Flex Hose	61A830410 (2)
Equalization Valve Screen Cap	61V830071 (1)
SUS Loop Heater (GFE)	
ATM Liquid Heater (GFE)	

- Additional MDAC-E Supplied IFM Spares for SL-4

Condensate System Quick Disconnect Plugs	52-83708-209 (3)
Cable Assy, "S" Band/AM Recorded Data	61A762367-1 (1)
Cable Assy, Mole Sieve Fan	61A762368-1 (1)
Cable Assy, Emerg/Tape Recorder Voice	61A762370-1 (1)
Saddle Valve Assembly	20M33247-1 (GFE) (3)
Hose Assy, Coolanol Servicing	61A830416-1 (1)
Hose Assy, Coolanol Servicing	61A830416-5 (1)
Tank Assy, SL-4 Coolanol Reservicing Module	61A830417-1 (1)
Repair Seal Assembly	61A830421-23 (3)
Pouch Assy (Contains Bolts and Spacers)	61A830423-1 (1)
SIA Load Connector Assy (SIA Variable Load)	61B850007-301 (1)
Paper Drive Assembly Kit	61B850018-33 (1)
Tone Generator Battery	61B880051-9 (4)
Adapter Assembly	1B96363-1 (1)
Tape Recorder Repair Kit	8556612 (RCA P/N) (1)
O-Ring (For PPCO2 Detector Block)	2-126 (Parker P/N)
	52-88715-125 (4)

FIGURE 2.16-2 TOOLS AND INFLIGHT SPARES

2.16.3.3 Postflight AVE Maintenance

Post Flight Maintenance Analysis Reports were made for each mission and provided a summary of Skylab Inflight Maintenance Analysis and a Maintenance Flight Log for each mission. AM engineering, mission report data and IFM Crew Systems debriefing comments were reviewed and analyzed to identify IFM support requirements including:

- IFM task description.
- Recommended IFM spares.
- Failure mode and effect analysis reference.
- Replaceability and accessibility.
- Fault detection and isolation capability.
- Maintenance environment and hazardous conditions.
- Estimated maintenance time.
- Crew utilization skill training.
- Stowage requirements and listing.
- Verification and checkout requirements.
- Tool and maintenance procedure requirements.

2.16.3.4 GSE Maintenance

Airlock Ground Support Equipment (GSE) Maintenance Summary, MDC PS Report 322, identified the periodic maintenance actions to be performed on the Ground Support Equipment associated with the Airlock Module of the Skylab program, including:

- Periodic maintenance
- Preventive maintenance
- Calibration
- Functional test
- Functional check

2.16.3.5 Storage

Storage Plan Airlock Flight Articles and Equipment, MDC PS Report)E501-12, presented a summary of storage requirements of the backup flight hardware (U-2), i.e., Adapter, Fixed Airlock Shroud, Deployment Assembly, Payload Shroud. It included Flight Article storage area requirements and GSE and spares storage requirements.

The maintenance technology group also provided KSC support during the preparation for U-1 launch by:

- Scheduling proof loading of all GSE lifting devices prior to shipment to reduce the work effort at KSC.
- Preparing baseline maintance requirements for use at KSC prior to shipment of the GSE from St. Louis
- Coordinating maintenance requirements with KSC Calibration Laboratories and other GSE work centers.
- Training personnel to support the maintenance requirements and scheduling effort at KSC.
- Physically reviewing all equipment for completeness prior to shipment and verifying that all required maintenance was performed prior to packaging for shipment.
- Coordinating National Bureau of Standards (NBS) calibration requirements and schedules on special GSE items requiring NBS calibration prior to use at KSC.

2.16.3.6 Conclusions and Recommendations

The degree of success of the Skylab space station can be attributed directly to man and his capabilities. Man and his maintenance ability was the key to the continued operation and success of all Skylab missions. Inflight Maintenance was the Master Key for the ingenious repairs, performed by the Skylab crew such as:

- By-pass of a docking problem, SL-2.
- Deployment of the disabled solar panel, SL-2.
- AM primary coolant loop servicing, SL-4.
- ATM C&D coolant loop gas removal, SL-4.

Based on the success of the Skylab mission and the maintenance activity, both planned and contingency, that contributed to that success, it is recommended:

- That, because inflight maintenance and hardware changeout proved to be much easier than anticipated, provisions for a much expanded maintenance activity be included in the basic philosophy of future missions - especially for internal equipment activity and long duration missions.

- That, because pressure suited EVA was also more effective and more easily accomplished than anticipated, increased EVA maintenance be planned. In addition, external vehicle design should include provisions such as universal attach receptacles for mating foot restraints, handholds, umbilical restraints, portable lights, etc., for contingency EVA tasks.
- That a larger complement of general purpose tools and equipments be carried on future space stations to allow a greater range of contingency maintenance and repair.

2.16.4 Program Spares Support

Contractor spares support was provided throughout the program for Systems test of Airlock U1 and U2 at St. Louis, checkout of U1 at KSC, common items for OWS 1 and OWS 2 at Huntington Beach and Airlock Trainers at JSC and MSFC.

Thirteen thousand (13,000) line items of support material (4,500 AVE/8,500 GSE) were provided during the program. Of these, four thousand (4,000) were obtained from NASA Gemini residuals at no cost to the Airlock program. Fifty-five hundred (5,500) items were shipped to KSC to support local issue for maintenance at that site. Over five hundred (500) items of bulk hardware were ordered and expedited to KSC upon their request due to problems encountered in local procurement.

- At time of U1 entering Systems Test 7,600 spares items were available.
- At time of U1 shipment to KSC 10,300 spares items were available.
- 10,000 spares items were stocked at St. Louis.
- 3,000 spares items were stocked at vendors (depot support).

Program spare parts requirements were documented in a Support Material List, MDC Report E5C1-3, which was updated and re-issued to MSFC every ninety days.

Approximately nine thousand (9,000) line items of residual MDAC-E spares were shipped to MSFC for storage in support of the checkout and launch of a second Skylab.

During critical test periods, Logistics Support personnel were provided to man the St. Louis spares Bondroom on a 24-hour, seven-day week basis.

In November 1972, a Dedicated Shipping Team was established to better support Skylab during the critical stage of checkout and launch at KSC. This team, consisting of key personnel from project logistics, manufactuirng, material, quality and shipping disciplines, was dedicated to the expeditious fulfillment of emergency requirements for support material from MDAC-FTC. The expediting of several hundred spares against site emergency requests precluded checkout delays due to non-availability of support material.

Special procedures were implemented to control over seven hundred spare parts subject to periodic retest on benches in St. Louis. These spares, located in bondrooms at St. Louis and KSC, were statused on a daily basis and scheduled into retest prior to shelf expiration dates to insure a serviceable spare on hand when needed.

The timely turnaround of reparables was a major factor in support of the program. Many equipment modifications dictated the modification of spares and the expedited changeout of hardware installed in U1 and U2. Over seven hundred (700) reparables and three hundred (300) modified spares were processed during the program.

2.16.4.1 Conclusions and Recommendations

The Airlock program was adequately supported throughout at a very low percentage of spares vs. end item hardware cost. The support philosophy of Contract Appendix E was particularly appropriate for support of the Airlock program; it provided the required flexibility and a maximum of support material at the lowest cost, with a minimum expenditure for documentation (paper). This support concept placed the responsibility for system support squarely upon the contractor with a minimum requirement for reviews and status documentation. The contractor was responsible for his designed equipment through build, test, checkout, launch support and orbital operation. The development of the necessary Ground Support Equipment (GSE), adequate terrestrial and orbital spares, replacement procedures and repair capabilities were pre-requisites of the support program.

Present day logistics technology dictates the utilization of computer programs, based upon detail maintenance analyses of systems/components, in the provisioning and allocation of support material on future programs. Contractor

capabilities are particularly appropriate in supporting high cost systems under his design control. Utilization of these capabilities is recommended for support of future space programs.

SECTION 3 RELIABILITY PROGRAM

The objective of the Airlock Reliability Program was to establish and attain a high level of equipment reliability to accomplish specified tasks during an eight-month Skylab mission.

The Airlock was the central control and supply module for the Skylab system, providing the necessary conditioned electrical power, environmental constituents and communication equipment for the Skylab.

The reliability necessary to achieve the program objective was established by defining qualitative and quantitative goals and then using these goals as guidelines for systems' design, product development, manufacturing and end use phases of the Airlock equipment.

During this period detected problems that required effective remedial engineering action or improved quality control were resolved by direct communication with Airlock management and responsible engineering disciplines. The cycle was completed when corrective action was determined and implemented by quality and manufacturing disciplines.

This approach was successful in the achievement of high mission reliability and maximum crew safety throughout the Airlock Program including the Skylab Mission.

3.1 METHODOLOGY

The major activities for achieving the necessary Airlock reliability were:

- Conducted a Failure Mode and Effect Analysis (FMEA) to identify critical modes of equipment failure in order to propose design changes to eliminate or minimize these failure effects, or to provide rationale for their retention.
- Prepared a Critical Items List (CIL) which included Single Failure Points (SFP's) derived from the FMEA, critical redundant/backup components, and launch critical components. The CIL identified primary components requiring test emphasis, contingency procedures and special management control.

- Prepared a reliability model containing quantitative assessment of mission reliability and crew safety for purposes of recommending design improvements to meet the Airlock reliability goals of 0.85 for mission success and 0.995 for crew safety.
- Conducted trade and special studies to optimize reliability for specific areas of interest.
- Conducted design reviews with the intent of recommending design changes to enhance reliability.
- Evaluated potential suppliers to determine their capability to furnish equipment having the required reliability and monitored supplier performance during the program.
- Reviewed test plans for adequacy to demonstrate required performance and reviewed test results to confirm that the required performance has been demonstrated.
- Established and implemented a controlled system for reporting, analysis, and correction of nonconformances.
- Investigated the applicability of NASA problem alerts to the Airlock Program, and if applicable, recommended corrective action or provided rationale for no action. Originated MDAC-E Alerts when recurrent parts, design, or manufacturing deficiencies were discovered in the Airlock Program which might have been applicable to other programs.

3.2 DESIGN EVALUATION

The Airlock design was evaluated to insure that the reliability goals could be met. The detail design of components, equipment, and systems was evaluated for:

- Their potential to perform as required.
- Single Failure Points (SFP's) which could jeopardize crew safety or mission success.
- Optimum redundancy.
- Fault isolation capability.
- Contingency operation.

3.2.1 Failure Mode and Effect Analysis

A Failure Mode and Effect Analysis (FMEA), MDC Report F673, was conducted on AM flight components, including the Payload Shroud, and on selected AM GSE. In

addition to the analysis of single failures, second failures of flight components within the same subsystem were also analyzed where the components provided identical or similar functions and the initial failure was undetectable by the crew or ground. Mission Essential GSE (that required to support Terminal Countdown 72 hours prior to SL-1 launch) was analyzed as was GSE used in any hazardous test or servicing operation. Figure 3-1 represents a sample page from the FMEA report.

The analysis documentation contained the following information:

- Component analyzed.
- Mission phase(s) in which the component could fail. (For GSE, the test or servicing operation in which equipment was used.)
- Failure mode evaluated.
- Most probable failure cause.
- Failure effect on the system and mission.
- Failure indication available to the crew and ground monitoring.
- Action available to the crew and ground to negate or minimize the failure effect.
- Estimate of maximum time the mission would be allowed to continue if the failure affects mission duration.
- Criticality classification of the failure effect.
- Recommended design changes, fault isolation capability, and checkout and operational procedures; particularly in regard to single failures which could adversely affect crew safety or the accomplishment of primary mission objectives.

3.2.2 Critical Items List

A Critical Items List (CIL), MDC Report E0365, was derived from the FMEA. The CIL was used as a basis for management control of Single Failure Points (SFP's) and mission critical hardware with emphasis on elimination of SFP's, where feasible. The CIL also provided an input for establishing test and checkout procedures, and contingency planning for critical hardware. Figure 3-2 represents a sample page from the CIL report.

The CIL contained the following groups of components:

- Single Failure Points (SFP) - Individual components whose failure could adversely affect crew safety or could result in not achieving a primary mission objective.

DATE 10 July 1970
REVISED 31 August 1971
REVISED 28 Feb. 1973 F

SYSTEM: ECS
SUBSYSTEM: THERMAL CONTROL

MCDONNELL
ST. LOUIS, MISSOURI

PAGE 4.1.20
REPORT F673, VOL. III
MODEL 1.03

COMPONENT	MISSION PHASE	a) FAILURE MODE b) MOST PROBABLE FAILURE CAUSE	FAILURE EFFECT a) SYSTEMS b) MISSION	CREW a) INDICATION b) ACTION	GROUND a) INDICATION b) ACTION	a) TIME TO ABORT (HRS) b) FAILURE CATEGORY	RECOMMENDATIONS
Pri or Sec. Power Supply Power SR relay (Any 1 of 8) K2-40, K2-91, K2-73, K2-140, K2-101, K2-103 K2-71, K2-13 Maintains Power for Latch & reset of the supply Power relay 4.1.15	M	a) Pole B fails open when relay coil is energized.	a) Coolant Pump Inverter cannot be deactivated when Inverter Switch is placed in "Off" position. Continuous voltage is applied to SR coil tripping C/B or burning out coil.	a) Ground informs crew that Inverter has not shut down.	a) TM indicates associated inverter is activated.	a) N/A	
		b) Insulating film on contacts due to particle contamination.	b) If inverter fails, redundant system is available.	b) Open applicable Coolant Pump Power Inverter CB to remove power from inverter.	b) Inform crew that inverter has not shut down.	b) IIIb	
	M	a) Pole A fails open when relay coil is energized.	a) Inverter cannot be activated when Inverter Switch is placed in "ON". Continuous voltage is applied to SR coil, tripping C/B or burning out coil.	a) Continuous C&W when pump switch is turned on.	a) TM indicates zero flow in loop and zero delta P across pump package. Zero inverter input.	a) N/A	
		b) Insulating film on contacts due to particle contamination.	b) None, redundant inverters available.	b) Activate a redundant inverter.	b) Advise crew of switching to turn on alternate pump-inverter.	b) IIIb	
	M	a) Latch or Reset coil fails open.	a) Loss of ability to change state of power supply power relay.	a) 1. For inverter fails "ON" C&W system alerts crew. 2. For inverter fails "OFF", ground alerts crew.	a) TM indicates pump and loop status.	a) N/A	
		b) Defective terminal or wire subjected to thermal or mechanical stress.	b) None, unless Inverter fails.	b) 1. If inverter fails "OFF" activate alternate inverter/ 2. If inverter fails "ON" open applicable CB.	b) 1. None if inverter fails "ON" in mission phase S. 2. Activate alternate inverter via DCS if inverter fails "OFF" during mission phase S. 3. Inform crew that inverter has not shut down if inverter fails "ON" during mission phase M.	b) IIIb	

FIGURE 3-1 FAILURE MODE AND EFFECT ANALYSIS REPORT – SAMPLE PAGE

MCDONNELL
ST. LOUIS, MISSOURI

DATE 12 March 1971
REVISED 5 January 1972 (A)
REVISED 11 December 1972 Rev. B

PAGE 5
REPORT MDC E0365
MODEL 1003

CIL GROUP Single Failure Points

AIRLOCK CRITICAL ITEM LIST

COMPONENT	SYSTEM/ FMEA IDENT.	FAILURE MODE	FAILURE EFFECT	FAILURE CATEGORY	CNTL. DISCPL.	RECOMMENDATIONS/RATIONALE/REMARKS	
Quadriplexer (52-85703) SPF No. 2.4.1	Comm. 2.4.17	Loss of output P5 to Discone Antenna Coax Switch.	Total loss of telemetered data resulting in early mission termination. $C = 167 \times 10^{-6}$ $B = 1.0$	II	1.1, 2.1, 3.1, 5.1	Use as is. The Quadriplexer is a passive device consisting of tuned cavities. This is a Gemini Flight qualified unit. "MDAC-East was directed per letter PM-SL-AL/MDA-1013-70 (9/18/70) to study. MDAC-East results provided by letter 646-E016-3800 (10/20/70). ASTR-EA requested to review per PM-SL-AL/MDA-1269-70 (11/15/70) and submit ECR if required. ASTR letter S&E-ASTR-SC-70-1/2 (11/30/70) recommends no change.	SCN 004
		Loss of output due to corona. (Included by NASA direction)	Temporary loss of telemetered data during ascent.	II	1.1, 2.1, 3.1, 5.1	Likelihood of problem occurring is small since the Quadriplexer is vented and applied power does not exceed test-demonstrated corona level until orbital altitude is reached.	SCN 002
Circuit Breaker, Magnetic "Earth Resources Panel Power" (STS Right Hand C/. Panel) (52-79721-312) SPF No. 6.5.1	EXP 6.5.10	Opens before normal break current is exceeded.	Loss of 28 VDC power to C&D panel which results in: a) Loss of EREP control power and all EREP experiments become inoperative. b) Loss of both EREP tape recorders. c) Loss of C&D Panel displays for all EREP experiments. $C = 12 \times 10^{-6}$ $B = 1.0$	II	1.1 2.1 3.1 5.1	Use as is with qualification. 1. C&D panel loads and power input wiring on the MDA side of the AM/MDA interface are nonredundant. Therefore, redundant power input lines on the AM side alone to eliminate this SPF is not justified. 2. If C&D panel loads can be split and isolated, then an independent input power source to each load grouping is desirable to reduce the number of EREP experiments lost in the event of the loss of one power input. 3. Existing AM power input design complies with the power input configuration requested for the C&D panel.	SCN 002
Relay, S.A. "EREP BUS 1" K6-271 (52-79715-13) SPF No. 1.2.2	EPS 1.2.62c	Coil or pole A fails open.	Loss of 28 VDC power to C&D panel which results in: a) Loss of EREP control power and all EREP experiments become inoperative. b) Loss of both EREP tape recorders. c) Loss of C&D panel displays for all EREP experiments. $C = 10 \times 10^{-6}$ $B = 1.0$	II	1.1 3.1 3.1 5.1	Use as is with qualification. 1. C&D panel loads and power input wiring on the MDA side of the AM/MDA interface are nonredundant. Therefore, redundant power input lines on the AM side alone to eliminate this SPF is not justified. 2. If C&D panel loads can be split and isolated, then an independent input power source to each load grouping is desirable to reduce the number of EREP experiments lost in the event of the loss of one power input.	SCN 002
Relay, Latching "EREP BUS 1 Power", K6-269(52-79713-13) SPF No. 1.2.3	EPS 1.2.62	Coil or pole C fails open.	(SAME AS SPF No. 1.2.2)	II	1.1 3.1 3.1 5.1	(SAME AS SPF No. 1.2.2)	SCN 002

FIGURE 3-2 CRITICAL ITEM LIST REPORT – SAMPLE PAGE

- Monitoring Systems - Monitoring system components whose failure in addition to failure of the operational system being monitored could result in loss of life of crew member. (Although no AM components satisfied this definition monitoring components associated with fire and rapid cabin pressure loss were listed.)
- Critical Redundant/Backup Components - Redundant components that provided a function which was required for crew safety or accomplishment of primary mission objectives.
- Launch Critical Components - Flight hardware used in the last 72 hours before launch whose failure would result in a launch scrub (recycle of the launch vehicle).
- Ordnance System Components - AM pyrotechnic devices

The CIL listed the following characteristics of each item.

- Failure mode.
- Failure effect.
- Criticality Category.
- Disciplines (quality, design, test, and procedures) imposed to control.
- Recommended design changes to eliminate or minimize the effect of failure.
- Fault isolation capability or checkout and operational procedures.
- Justification for retention if SPF was not eliminated.

Some of the SFP's eliminated as a result of this analysis were:

- Spare condensate module was provided to eliminate condensate collection SFP.
- ATM deployment mechanism trunnion bearing outer race retention force was sized such that in the event of inner race binding, the available torque during deployment was sufficient to rotate the outer race as a backup rotating mode.
- Flow limiters were incorporated into the delta pressure transducers' sensing port lines which extend through the cabin wall to eliminate five potential rapid cabin leakage SFP's resulting from diaphragm rupture of the transducers.
- An inadvertent AM DCS "MDA Vent Valve Open" command or premature operation of the associated command channel relay could have prematurely opened either one of two MDA vent valves, which at this point in the design phase were configured in parallel. This DCS command was eliminated by changing the

MDA vent valves to a series configuration, opening both vent valves prior to lift-off, and using redundant IU commands to close the series valves prior to orbit insertion.

Only three SFP's which could jeopardize crew safety were identified in the final AM design as a result of the FMEA. Although elimination of these SFP's was not feasible, the following actions were taken to minimize their likelihood of occurrence:

(1) External leakage of coolant fluid from the coolant system loop inside the pressurized area - possible fire hazard if the leak was in presence of an ignition source within cabin area.
Action - A special "Coolant System Assurance Plan" (MDC Report E0294), which rigorously controlled the design, procurement, manufacturing, quality surveillance, testing, maintenance, and operational procedures of the coolant system was implemented to assure the highest possible configuration reliability. Ignition sources were also isolated from potential coolant leak areas.

(2) Burst of any one of six O_2 tanks - possible loss of cluster stability resulting in cluster break-up.
Action - Tanks constructed of heavy cross filament winding about a thin steel liner. Testing demonstrated that any pressure release would be by diffusion through the winding rather than abrupt rupture of the tank wall. Vendor acceptance proof test at 7530 psig was followed by MDAC-E acceptance test at 5000 psig. Nominal operating pressure was 3000 psig.

(3) Burst of any one of six N_2 tanks - possible loss of cluster stability resulting in cluster break-up and/or shrapnel.
Action - Design burst pressure was 6660 psig (twice operating pressure) and acceptance testing was at 5000 psig.

In general, the existing SFP's which could result in loss of a primary mission objectives fell into the following broad categories:

- Fluid systems flow restriction or leakage.
- Passive electrical component failures - quadriplexer, connector opens and shorts, and buses short to ground.
- Relay and circuit breaker failures resulting in loss of EREP (defined as primary objective after design commitment).

- Mechanical failure of hatches or leakage of seals.
- Premature operation of manual switches or latching relays.

3.2.3 Reliability Model

At the beginning of the Airlock Program, Airlock reliability goals of 0.85 for mission success and 0.995 for crew safety were established where:

(1) Mission Success was defined as having the Airlock Module function as necessary to support:
- Planned duration of all habitation phases.
- Revisitation after orbital storage.
- Planned two-man EVA's.
- ATM experiments.
- Earth Resources experiments.
- Biomedical experiments.

(2) Crew Safety was defined as having the Airlock Module function as necessary to permit the crew's safe return throughout the planned mission operations.

Early in the program, when the Airlock Systems were initially conceived, the reliability of each system was estimated to identify equipment and system configurations which required design improvement in order to meet the quantitative reliability goals. System improvements resulting from this early analysis were:

System Improvement Identified and Implemented	Date of Identification
Communications - Provided redundant DCS	2 February 1967
Instrumentation - Provided redundant programmers	24 February 1967
Electrical Power - Provided internal redundancy in voltage regulator and battery charger	27 March 1967
ECS - Provided redundant molecular sieves	29 June 1967

This assessment was subsequently formalized in a reliability model (MDC Report G815) containing Airlock mission reliability and crew safety estimates. The model consisted of simplified system logic diagrams, failure rates and equipment duty cycles used, and calculated results by mission phase. The model was initially submitted to NASA on 10 July 1970, and was updated for each formal spacecraft review thereafter, with a final report issued on 16 February 1973.

The final Airlock Module estimate for mission success was 0.83. This ordinarily would indicate that Airlock design did not meet the 0.85 reliability goal. However, it should be noted that when the reliability goal of 0.85 was established early in the Airlock Program, EREP and Biomedical Experiments were not primary mission objectives. The Airlock Module does meet the reliability goal based upon the original definition of SWS mission success which did not include accomplishment of EREP or Biomedical Experiments. Airlock Module reliability based upon this original definition of SWS mission success is 0.86.

Crew safety reliability was estimated to be greater than 0.9999 which exceeds the safety reliability goal.

3.2.4 Trade and Special Studies

Reliability trade and special studies were conducted during the AM design phase to determine desirable systems reliability improvement or to confirm acceptable reliability of existing design. Some of the reliability improvements that resulted from these studies were:

- Redundant tracking lights installed.
- Redundant voice communications audio hardlines installed.
- Four stowed spare PCM tape recorders provided to compensate for the anticipated operational life limitation of the recorder.
- Redundant electronic timers installed to increase reliability of the switchover function to the backup DCS and the recorded data time correlation function.
- A third coolant pump and inverter were added to each coolant loop to maintain acceptable thermal control system reliability after it was determined that two pumps instead of one would normally be required to operate continuously during all manned mission phases.
- Six stowed spare UV detectors provided as backup for the 22 installed detectors throughout Skylab. Two stowed spare Fire Sensor Control Panels were provided as backup for twelve FSCP's installed throughout Skylab.
- Redundant volume compensators provided to prevent overpressurization of heat exchangers by coolant trapped in the ground coolant system.
- Redundantly interconnected latch actuators installed for release of the stabilization struts between the upper and lower truss for ATM deployment.

- Redundant Time Correlation Buffers installed to increase reliability of AM Time Reference System.

In addition to the above studies that resulted in configuration changes, a study was performed which confirmed that relay contact chatter, if it should occur during the launch/ascent phase of SL-1, would have no adverse systems or mission effect.

3.2.5 Design Reviews

Formal and informal design reviews were conducted to systematically assess equipment design with respect to its ability to meet specified requirements. Formal reviews with prepared agendas were attended by cognizant personnel from Design, Technology, Reliability, Quality, Materials and Processes Groups, etc. Review meeting minutes and follow-up action items were published.

Preliminary reviews were conducted to ensure that equipment requirements were clearly and completely defined in the equipment specifications and were consistent with system and program requirements. Detailed reviews were conducted after the detail design was established to assure that the design met specification requirements and was acceptable for release to production. The basic review tasks were to analyze and evaluate design concepts, layouts, schematics, drawings, and test results in sufficient detail to ensure that the design adequately reflected consideration of requirements related to performance, reliability, environmental effects, weight, producibility, interchangeability, and maintainability. Formal design reviews were conducted on the voltage regulator, battery charger, ATM film transfer boom, digital command system, shunt regulator, speaker intercom assembly, audio load compensator, and electronic light dimmer. Typical actions resulting from these reviews were:

- Stricter electronic parts specifications to assure high quality parts.
- Packaging changes for improved access to internal parts.
- Clarifications, corrections, and added details to production drawings.
- Rerouting of wiring and electrical harness.
- Reorientation of parts in assemblies to minimize the possibility of manufacturing errors.

3.3 SUPPLIER EVALUATION

Potential suppliers of critical equipments were evaluated prior to award of a subcontract to determine their capability to furnish equipment having the required reliability. The evaluation included such elements as consideration of past experience with the supplier, assessment of his proposed design, visit to his facility, and evaluation of his management, engineering, and quality personnel, and the proposed organization for the AM Program.

After subcontract award, the supplier's performance was monitored throughout the program to ensure compliance with the reliability requirements. When deemed necessary, MDAC-E Reliability, Design, and Quality personnel visited the supplier's facility to resolve problems. In addition to selective visits, a comprehensive joint NASA/MDAC-E survey of the facilities and operations of all 32 major subcontractors was conducted between 20 July 1970 and 13 July 1971 to verify the production of high quality equipment and to identify deficiencies requiring corrective action. The dominant improvement actions required as a result of the survey were:

- Housekeeping and cleanliness improvement.
- Hardware handling and protection improvement.
- Test equipment calibration.

All discrepancies found were corrected which, in turn, increased the confidence in obtaining high quality equipment.

At the time of the surveys, guidance was also provided in the areas of Manned Flight Awareness. Various related motivational materials were provided to the supplier companies such as: Mission Timelines, Posters, Stickers, etc.

3.4 TEST REVIEW

Qualification, acceptance, and system test plans and test results were reviewed to evaluate and confirm test adequacy for demonstrating compliance with design, performance, and workmanship requirements. In conducting these reviews, the following were considered:

- Adequacy of the test to confirm design margins and reveal marginal design characteristics.
- Sufficiency of exposure to combinations of extreme environmental conditions during the test.

- Appropriateness of the test article configuration to provide valid test results.
- Adequacy of pre-test checkout to verify operational performance of the test article and provide a baseline for comparison to test results.
- Adequacy of post-test checkout to provide comparison to pre-test condition.
- Sufficiency of test instrumentation to measure, record and monitor all applicable parameters at a frequency to obtain complete test data.
- Effects of operational stresses, storage, shelf-life, packaging, transportation, handling, and maintenance.
- Necessity and scope of retest resulting from test problems.
- Follow-up of test failures and subsequent testing to assure that corrective or preventive action was satisfactory.

A continuous and documented assessment was made to identify differences between qualification and flight configurations of those components requiring qualification tests, and determine the effect of these differences on the components' qualification status and the need for qualification retest. Most of the differences found between the qualification test units and flight units were the replacement of a few electronic parts in the flight configuration with parts similar to those in the qualification test configuration, but of improved quality and reliability. The qualification tests were considered to have remained valid, with these part changes.

Some instances where portions of the qualification tests were repeated because of post-test configuration changes were:

(1) UV Sensor (61B880060) - Resistor, capacitors, and diode added for turn-on transient suppression. Repeated EMI test and vibration test since dynamics of the sensor changed due to the addition of terminals for mounting the additional parts.

(2) Gas Flowmeter Converter (61B880058) - Added resistor and thermistor in parallel with an existing resistor for fine tuning of the temperature compensation circuit. Repeated low temperature, temperature-altitude, and life test.

(3) Teleprinter (61B850018) - Redesigned teleprinter cartridge bearings, motor rotor and bearings, and added lubricants and sealing materials Extensive requalification testing was performed (vibration, humidity, low-temperature, temperature-altitude, salt spray, noise, O_2 environment, and EMI).

3.5 NONCONFORMANCE REPORTING, ANALYSIS, AND CORRECTIVE ACTION CONTROL

A closed loop system for nonconformance reporting, analysis and corrective action control applicable to AM hardware and mission essential and hazardous GSE was established. Functional failures of AM hardware occurring during in-house development, all qualification and production test functional failures, and non-functional defects which could have a significant impact on program schedule, hardware performance, or safety were subject to systematic reporting, analysis, and corrective action control. One thousand ninety-one nonconformances were processed during the AM Program period of performance. Figure 3-3 shows the flow of reporting, analysis, and corrective action.

Nonconformances were analyzed at the vendor's plant, at MDAC-E or at KSC depending on the nature of the anomaly, place of anomaly occurrence, and availability of appropriate facilities. Complex equipment was returned to the vendor when the analysis required specialized engineering and technical skills or special equipment. The MDAC-E laboratory, which is equipped with precision measuring devices, environmental chambers and sensitive detectors, performed detailed functional, physical, and chemical analyses to provide rapid determination of failure causes. By the program's end, the MDAC-E laboratory had performed 540 analyses.

Final analyses and recommended corrective actions were subject to approval by MDAC-E Reliability and by MDAC-E Design, GSE, or Quality Engineering and by the NASA.

Some examples of failures which had a significant technical or program impact are discussed below.

3.5.1 Thermal Control System

A series of failures to restart the 61C830069 water pump used in the ATM and SUS coolant loops occurred as a result of corrosion, contamination, and formation of deposits.

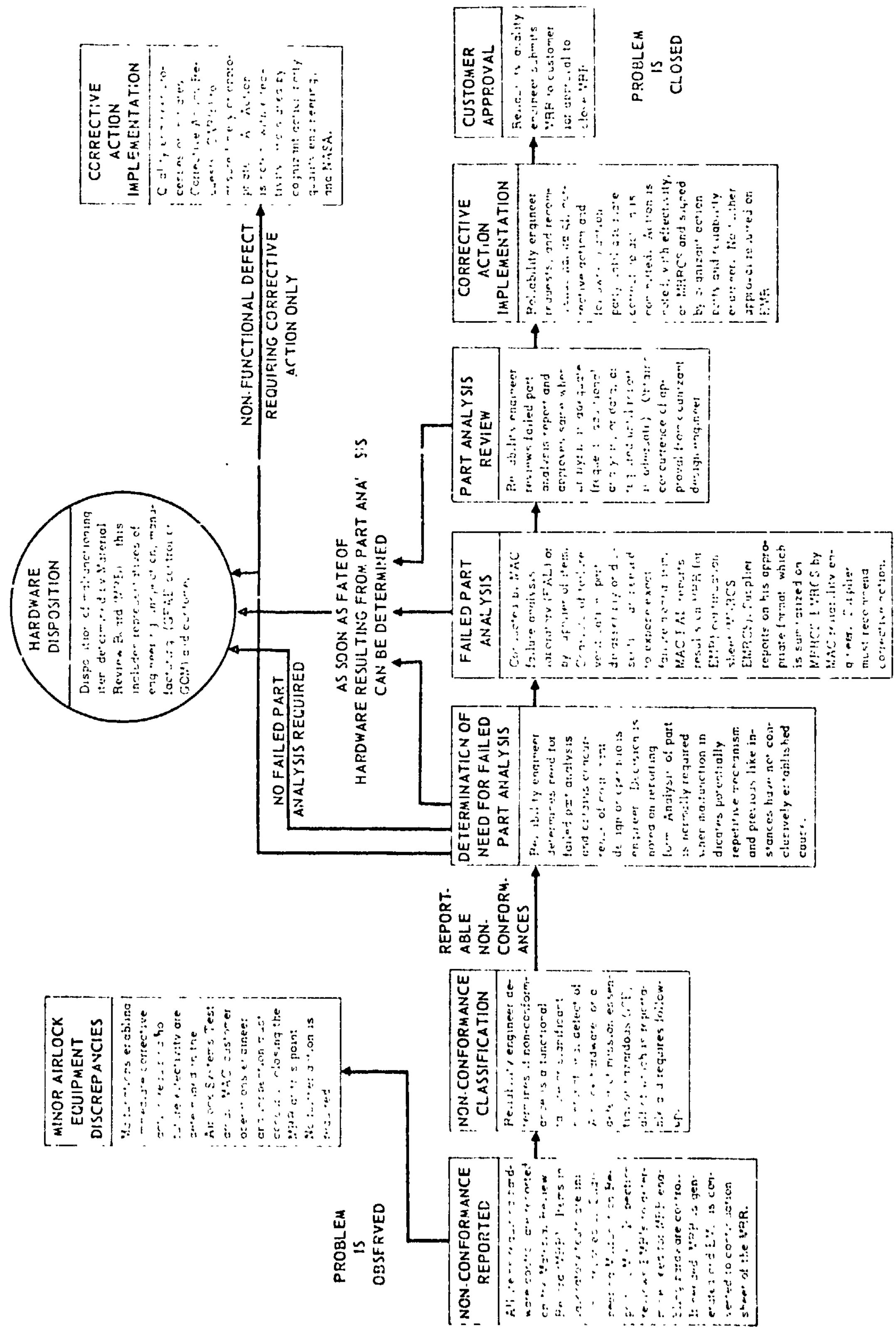


FIGURE 3-3 NONCONFORMANCE REPORTING, ANALYSIS AND CORRECTIVE ACTION

Corrective Actions

(1) Changed material of the rotor and liner from tungsten carbide to Colmonoy No. 6 to eliminate corrosion (Both ATM and SUS pumps).

(2) Flushed pumps with isopropyl alcohol followed by vacuum drying after pump removal from a wet system to remove residual particles (ATM and SUS pumps).

(3) Improved cleanliness controls, including 0.45 micron filters in final flushing, incorporated at vendor facility to prevent introduction of foreign particles into the pumps (ATM and SUS pumps).

(4) Changed corrosion inhibitor from K_2HPO_4 to sodium chromate to prevent the formation of particles which was caused by the reaction of K_2HPO_4 in the water solution with nickel from the system with silver from the bactericide, Movidyn, acting as a catalyst (SUS pumps only).

(5) Increased clearance between pump vanes and rotor slots to increase tolerance to small particles (SUS pumps only).

3.5.2 Communications System

Nineteen SM709G Integrated Circuit (IC) operational amplifiers used in the 61A850003 Speaker Intercom Assembly and the 61A850004 Audio Load Compensator had degraded input transistors as a result of electrical overstress of their emitter-base junctions. The IC's were damaged by electrostatic charge generated during manufacturing of printed circuit board (PCB) assemblies.

Corrective Action

To prevent electrostatic charge buildup during PCB assembly manufacture, the following procedures were implemented:

(1) Applied an antistatic coating to the plastic potting molds.

(2) Completed assemblies were stored in aluminum foil to reduce the possibility of a buildup of an electrostatic charge.

(3) Instituted special handling during the manufacturing assembly of the units which consisted essentially of grounding the work station, operator, and tools.

Microsemiconductor JANTX 1N4245 Diodes failed "Open" intermittently during test of the 61B850005 Command Relay Driver Unit (CRDU). Failure was caused by the inability of the glass case, which was used to maintain electrical continuity by holding the diode stud and chip in compression, to provide the required compression. An Alert, originated by MDAC-E, was issued by the NASA on this problem.

Corrective Action

All of the above diodes used in existing flight units were replaced with Semtech JANTX 1N4245 diodes which have the diode stud and diode chip metallurgically bonded. This resulted in replacement of 1924 diodes in each existing CRDU, 14 diodes replaced in each 61B850019 interface electronics unit, and 118 diodes replaced in each 61B850012 caution and warning unit. The Semtech diode was used in all new-build units.

3.5.3 Instrumentation System

A test PCM Programmer exhibited excessive errors on all high level analog channels as a result of change of resistance in a metal film resistor. Investigation indicated an inherent design deficiency with this type of resistor which used talon lead construction. Voids existed between the resistive element and the lead connection.

Corrective Action

Talon lead resistors in all programmers, mole sieve cycle timers and temperature controllers, and AM tape recorders were replaced with resistors using end cap construction.

3.5.4 Electrical System

NiCad battery cells shorted as a result of pressure points within the cell caused by positive plate growth and poor tab alignment.

Corrective Action

(1) Increased clearance between the top of positive plates and tab or adjacent negative plates.
(2) Increased coined area along plate edges.
(3) Eliminated cell holddown and plate bending in the tab area.
(4) Added strain relief in the tab to header attachment.
(5) Improved cell plate to tab alignment.
(6) Provided new tab shaping, holding, and welding fixtures.
(7) X-rayed all cells for proper alignment of cell plates and tabs.

3.6 ALERT INVESTIGATIONS

The applicability of NASA Problem Alerts to the Airlock Program was investigated. Upon receipt of the Problem Alert from the Resident NASA Office, MDAC-E Project personnel initiated a survey of in-house, subcontractor, and supplier programs to determine the usage and significance of the problem parts, materials or processes in the Airlock Program. The Resident NASA Office was notified in writing of the Alert applicability to the Airlock Program. Recommended action or rationale for no action was submitted as applicable. In addition to the investigations of Alerts originating from outside sources, MDAC-E originated some alerts as a result of recurrent parts, design, or manufacturing deficiencies discovered in the Airlock Program. These Alerts were drafted by MDAC-E and submitted to NASA for release as NASA Alerts. Figure 3-4 summarizes MDAC-E originated alerts.

The scope and results of the MDAC-E investigations of Alerts during the entire Airlock Program were:

Total number of Alerts processed - 512.
Number of Alerts found applicable to the Airlock Program - 50.
Number of Alerts prompting design or process changes - 31.

Problem alerts which caused Airlock changes include the following:

(1) Problem - Solid tantalum capacitors failed by shorting due to reflow of internal solder caused by excessive heat during retinning operations or installation into equipment.
Action Taken - X-rayed all uninstalled PC boards with solid tantalum capacitors attached. Since AM manufacturing cycle for PC boards was complete at time of Alert issuance, no additional C/A was incorporated.

(2) Problem - Trent Tube Co. Stainless Steel Tubing had stains and pits on the ID surface due to inadequate control of pickling, rinsing, and/or drying procedures at the tube manufacturer.
Action Taken - Lines inspected and replaced on an as-required basis.

ALERT NO.	DATE	PROBLEM	CORRECTIVE ACTION
MSFC-71-1	1-6-71	MICROSEMICONDUCTOR CORP. DIODES (JAN IN3206) EXPERIENCED FAILURE OF CRIMPED KOVAR LEADS AT DIE.	REPLACED IN AIRLOCK EQUIPMENT.
MSFC-71-4	5-17-71	MICROSEMICONDUCTOR CORP. DIODES (JAN TX IN4245) FAILED OPEN DUE TO COMPRESSION BONDING TECHNIQUES.	REPLACED IN AIRLOCK EQUIPMENT.
MSFC-71-9	6-8-71	CUTLER-HAMMER TOGGLE SWITCHES FAILED TO RETURN TO PRESWITCHED POSITION DUE TO DEFECTIVE CONTACT PRESSURE SPRINGS.	REPLACED IN AIRLOCK EQUIPMENT.
MSFC-72-20	10-26-72	AEROVOX CAPACITORS (FLA 21) HAD CRACKING OF CERAMIC, AND CERAMIC TO PALLADIUM-SILVER FRIT SEPARATION.	REPLACED IN AIRLOCK EQUIPMENT.
MSFC-72-22	11-7-72	ENSIGN BICKFORD. PETN DETONATING CORD EXPERIENCED LONG TERM SHRINKAGE.	REPLACED IN PAYLOAD SHROUD EQUIPMENT.
MSFC-72-28	12-26-72	SNAP-TITE INC. QUICK DISCONNECT (15 & 29 SERIES) FAILED TO LOCK DUE TO INCORRECT COIL SLEEVE SPRING LENGTH.	REPLACED IN AIRLOCK EQUIPMENT.
MSFC-73-3	2-15-73	TANSISTOR ELECTRONICS CAPACITORS CL53BL101UPG, CL53BJ181UPG HAD CONDUCTIVE PATH BUILD UP FROM POSITIVE TERMINAL TO CASE DUE TO CORROSION.	REPLACED IN AIRLOCK EQUIPMENT.

FIGURE 3-4 MDAC-E ALERT SUMMARY

(3) Problem - Metal film resistor manufactured by Vamistor Corp. increased in resistance due to migration of metal film.
Action Taken - Vamistor resistors were replaced in two spare Speaker Intercom Assemblies, in PC boards not yet coated or potted, and in equipment requiring rework where the coating/potting was removed in the area of the resistors. All stock was purged of this part and its future use prohibited.

3.7 MISSION RELIABILITY

Airlock Systems successfully performed their required functions to support the accomplishment of planned mission duration and mission objectives.

The Airlock's ability to continue to function satisfactorily after anomalies had occurred within its systems was demonstrated during the mission. Appendix E provides a complete listing of mission anomalies and their mission impact, exemplifying the designed-in reliability.

3.8 CONCLUSIONS AND RECOMMENDATIONS

The Airlock Module demonstrated satisfactory reliability in the Skylab Mission. The successful Airlock performance indicated that an appropriate Reliability Program was implemented.

To enhance the reliability of future long-duration earth orbiting manned space laboratories, it is recommended that in-flight repair, maintenance, and component replacement capabilities (not requiring EVA) be maximized. The maximization of these capabilities would:

- Reduce the risk of mission failure. In-flight repair and replacement capability provides the flexibility to recover from failures which may occur at an unexpected high rate and which would otherwise be cause for mission termination if they occurred in a system of fixed built-in redundancy.
- Relieve the requirement to design and demonstrate equipment for extended life capability in longer duration missions.
- Reduce systems complexity by eliminating the need for switchover mechanisms and duplicate installations which would be required for multiple build-in redundancy design.

SECTION 4 SAFETY PROGRAM

The Airlock Safety Program was established to meet the requirements of the Airlock Systems Safety Plan, MDC Report G671. This plan was prepared to provide the safest practical means of performing all functions to bring the Airlock from the design stage through altitude chamber testing, shipment to KSC and the launch preparations and testing at KSC, without injury to personnel or damage to equipment. In addition to the prelaunch activities, the plan provided guidance for a practical approach to Airlock crew and system safety during the manned phases of the mission. The development of the Hazards Identification (MDC Report E0774), provided the necessary information for design engineering to prepare procedural and equipment work-arounds. These were to be utilized during the mission, should equipment failures occur that would jeopardize the safety of the crew or could cause an early termination of the mission.

An Airlock Safety Officer was assigned to insure compliance with the Airlock Systems Safety Plan and to provide additional guidance in areas involving potentially hazardous operations not specifically covered in detail by the plan. During the entire Skylab Program only one reportable accident (as defined by MMI 1711.2A) occurred on the Airlock development and test programs in St. Louis. An employee received a broken leg while assisting in movement of an item of test equipment. As a result of this accident, more stringent control procedures were established for handling and transport of high value, heavy and fragile Airlock equipment. These control procedures were formulated in CP 6.800 AE. After implementation of these procedures, no reportable accidents occurred.

4.1 GROUND PERSONNEL AND CREW SAFETY

4.1.1 Design Phase

During the design phase, Airlock Reliability reviewed all systems and prepared a comprehensive Failure Mode and Effect Analysis (FMEA). This document categorized the possible Safety/Reliability impact of the failure of each component in the system. Reliability, Systems Safety and design groups jointly reviewed results of these analyses for need of redesign for crew safety. A

single failure point list (SFP) was derived from the FMEA and used as a basis for determining the feasibility of eliminating single failures which could jeopardize crew safety, or if elimination was not feasible, to assure that adequate actions were taken to minimize the probability of occurrence of such failures.

To provide for maximum safety during AM systems testing, all ground support equipment designs and procedures (GSE) used to service the AM with high pressure gases were reviewed. Further, all GSE used inside the AM pressurized area during manned altitude chamber testing was reviewed.

Early in the AM program, a flammability and offgassing control procedure was implemented to restrict the amount of flammable materials used in the vehicle. In connection with this procedure, an accounting system and a materials review program were established.

Assurance of AM material compatibility was provided by review of engineering drawings and/or materials lists. The review assured compliance with applicable flammability, offgassing, O_2 compatibility and stress corrosion requirements per MSFC-SPEC-101A, MSFC-SPEC-106B and 10M33107, as implemented by the AM contract.

The basis of material approval was either test or analysis of similarity to existing test data. Maximum use was made of NASA test data from MSFC, JSC and White Sands, but where possible this data was supplemented by applicable contractor test data and/or by additional testing.

Implementation of the materials review program resulted in significant AM safety improvements. The following reflects some of the major safety improvements incorporated on the AM.

A. Early in the AM program, testing was conducted to determine the flammability characteristics of silicone/phenolic fiberglass laminates. This testing indicated that no ignition of these materials would result when tested with the standard ignition source. However, subsequent testing in conjunction with MSFC Materials Division inputs identified these materials to be "configuration sensitive". In

addition, it was determined that once ignited, these materials could support combustion to complete consumption rather than self extinguish. Since major module covers and ducting were fabricated of these materials, it was determined that the applications represented "fire propagation paths" and should be deleted. As a result, a design change was initiated to utilize polyimide fiberglass laminates for pressurized compartment covers and ducts in lieu of the silicone/phenolic fiberglass laminates.

B. Baseline MDAC-E wire bundles were covered with Teflon convoluted tubing for flammability protection. Preliminary testing of this configuration yielded satisfactory results. Later evaluation of this configuration with MSFC Materials Division produced data indicated that this type of flammability protection was deficient. After a survey of available techniques coupled with a test program, it was decided that the best solution was to utilize a newly marketed material called NBG (a fluoroelastomer) to cover the wire bundles. As a further safeguard against flammability, a system of either beta cloth covers or metal covers for potted switches and plugs was developed. All systems were thoroughly tested, thus demonstrating the AM wiring system capability of absorbing enough energy to fuze the heaviest conductors without flame propagation.

C. The survey of AM materials used in the high pressure O_2 system led to certain changes which provided increased compatibility with LOX impact sensitivity requirements. As a result, ignition sources in the O_2 system were minimized.

D. The baseline AM utilized O_2 as the fluid media to power certain functional systems such that if a leak occurred, any buildup in the habitable environment would be O_2 rich. The system was thus "fail safe." With the decision to utilize only those materials in the high pressure O_2 system which are compatible with LOX, this "fail safe" philosophy was reviewed. It was concluded that simply changing the fluid media from O_2 to N_2 to power these functional systems would be cheaper and that the safeguards which existed to prevent an N_2 rich atmosphere were adequate without modification.

E. Flight spares stowage on MDC space vehicles previous to AM was provided by encapsulation of the spares in a foam-in-place polyurethane and then placing the composite into a stowage container. It was demonstrated that if ignition of polyurethane occurred in a relatively tight container, rupture due to over pressure could result. Again, to enhance crew safety, a design change was initiated. After an unsuccessful search for a nonflammable foam, a "hard mount" design approach was followed which met the flammability requirements. In addition, some items were stowed in cutouts in stacked mosite rubber pads. Mosite, a closed cell foam, demonstrated adequate inflammability characteristics.

F. The baseline interior paint used on the AM was the same as that used on Gemini and Apollo, velvet coat. With the extended mission planned for Skylab, it was felt that the offgassing rate of velvet coat paint was potentially hazardous. Therefore, a paint evaluation program was initiated. This evaluation resulted in a change to Laminar X-500 paint which exhibited offgassing characteristics more suitable to long manned missions. The use of this paint entailed a development program to provide acceptable application methods on both metal and fiberglass substrates.

G. Flammability testing of early coolant line insulation designs resulted in complete combustion of the insulation materials. Since the configuration was not of a nonigniting or self-extinguishing nature, each insulated line represented a fire propagation path through the vehicle. Several updated designs were flammability tested in an effort to create a nonflammable design meeting all other considerations. The selected system consisted of a mosite layer covered by 2 wraps of aluminum foil tape followed by a wrap of beta glass tape.

H. A review of metals for compliance with stress corrosion guidelines established from a NASA development program was performed. This review resulted in changes in materials/design to eliminate potential safety hazards. For example: Changes were made to heat treatment procedures for the DA tube-end forgings to eliminate the stress corrosion possibility that could result in launch hazards connected with cracked forgings.

Coolanol 15, which was utilized as the heat transfer fluid in the Airlock and OWS cooling systems, was regarded as being hazardous due to flammability and toxicity. During extensive testing and review of the test data and laboratory data from other organizations, it was determined that Coolanol 15 was difficult to ignite in a pooled form. It was also established that ignition sources on the Airlock were isolated even if a leak did occur. The flight crew safety could not be endangered from contact with Coolanol 15 except by inhalation of vapor in the habitable compartment atmosphere if elevated temperatures were involved. Even though it was decided that the use of Coolanol was an acceptable risk, a Coolanol control plan was released to establish special controls during assembly of the coolant system. In addition, Coolanol spillage clean-up procedures were developed and implemented.

A study was conducted by the System Safety Officer to determine the flame propagation characteristics of the Molecular Sieve and Condensing Heat Exchanger Components and to determine what results could be expected if a fire occurred in a Mole Sieve. It was found that the probability of fire propagation was extremely low and it was highly unlikely that the crew would be endangered if a fire did occur in either the Condensing Heat Exchangers or Mole Sieves. The results of this study were released to the NASA in MDAC-East Safety Technical Note E261-1.

GSE and spacecraft design engineering reviewed all GSE and Airlock systems hardware designs to determine whether or not the hardware complied with the MSFC furnished Skylab System Safety Checklists SL-003-001-2H and SA-003-002-2H. GSE Engineering reviewed over 450 items of GSE hardware and Airlock Design Engineering reviewed all Airlock, FAS, DA and PS systems. All completed checklists were reviewed by Safety and each noncompliance item was evaluated with respect to its possible effect on safety to ground test personnel, the flight crew and hardware. This effort resulted in some minor design changes to GSE hardware and one change to AM flight hardware (fuse size change in Fire Sensor Control Panel) and several changes to test procedures to improve safety. Overall, the noncompliance areas of flight hardware did not result in unacceptable risks to crew safety. Subsequent GSE hardware changes were also reviewed to determine compliance with the Safety Checklists. Noncompliance items were

reviewed by Systems Safety. Subsequent changes to AM flight vehicle hardware were reviewed by AM Systems Safety to determine whether any general safety problems were introduced. During both these GSE and Airlock flight hardware follow-on review efforts, it was determined that none of the noncompliance items of the GSE Safety Checklist or changes to the Airlock flight hardware would cause an unacceptable risk to the flight crew. The checklists are considered to be of value as safety guidelines for future design efforts.

Early in the design program, Safety noted that many NASA contractors used different color codes for identification of live and expended ordnance. This situation would have caused confusion at KSC when ordnance items were being installed or handled and would have generated serious safety hazards. MDAC-E Safety coordinated this problem with MSFC NASA personnel involved in supply of ordnance for the Skylab Program. This resulted in an acceptable color coding for Airlock Module Deployment Assembly and Payload Shroud ordnance and proper labels to identify live, expended and test loaded ordnance. Additionally, NASA was made aware of the overall problems of different color coding procedures used by various contractors and the possible hazards this could create.

Design Engineering and Airlock Safety conducted a review of all Airlock pressure vessels and major components in pressure systems. This review was conducted to insure that this hardware was of proper design strength and would be adequately verified by test to insure personnel safety during testing and mission operations.

During the Airlock Critical Design Review the Airlock Safety Officer presented a review of the Airlock Safety Program and discussed all major safety efforts conducted during the design phase. An informal handout containing extensive details of the Safety Program and Safety accomplishments was distributed to NASA at this meeting. A preliminary Hazards Analysis Report was presented as part of this package.

4.1.2 Testing Phase

Prior to the start of the Airlock test program, the Airlock Safety Officer reviewed the test procedure index and established a requirement for his review and approval of certain test procedures. These procedures were those that involved high energy levels or dealt with hazardous materials. In addition, Airlock Safety reviewed all procedures to determine whether potential safety hazards were induced by procedure requirements and recommended procedure changes if required to maintain test safety. Procedures for handling, transportation and test were also reviewed by Safety.

During Airlock development, Airlock Safety worked with the Engineering Design Groups to identify all potential hazards associated with the design of the Airlock hardware where such potential hazards might be encountered during testing or during the mission. The identified potential hazards were reviewed with Airlock Management personnel and a final formal report (MDC Report E0774) was forwarded to MSFC for review at the Flight Readiness Review. This report contained two sections. The first section contained a listing of all identified potential hazards with a review of action taken to eliminate or minimize the possible hazardous effects. The second section contained a listing of residual hazards created by necessary energy levels or functions required for the mission that could not be eliminated at the time of launch. A careful evaluation of these residual hazards was conducted by Airlock Safety and it was concluded that each of these hazards fell into the category of acceptable risk to the crew.

A requirement was established that, during the entire test program, handling or transport of any of the Airlock modules would be accomplished only after the Airlock Safety Officer inspected all hoisting and handling equipment and provided written approval to proceed. All such handling and transporting operations were monitored by Airlock Safety.

During the Airlock test program, Airlock Safety inspected all test setups and monitored all testing where high energy levels were involved and hazardous conditions could develop. This effort insured that all safety requirements were complied with and that minimum hazards to personnel existed.

Airlock Safety prepared written requirements to insure safety for test personnel and flight crew during pressure test operations. These requirements were released in MDC Process Specification 21015.

During the period of planning for altitude chamber testing of the AM/MDA, Airlock Safety conducted an inspection of 30-Foot Altitude Chamber and Hyperbaric Chamber facilities to determine if chamber hardware was in conformance with the requirements of Section 10 of the Airlock Systems Safety Plan. All non-conformance items were reported to the Operational Readiness Inspections (ORI) Committee for evaluation and appropriate action. Key Test Operations, Airlock Safety and Life Support personnel attended ORI Committee meetings to furnish information and support the ORI Committee in their evaluations of the action required to bring all test facilities to a condition that insured a safe manned altitude chamber test.

GSE Engineering conducted a study of the effectiveness and characteristics of all available fire suppression systems to determine the optimum system to be used to support both manned and unmanned altitude chamber testing. The results of this study were reviewed with Airlock Safety. The most effective and safest system was jointly selected and recommendations for use were made to the ORI Committee.

Airlock Reliability performed and documented an integrated AM/MDA/GSE/Altitude Chamber/Facilities Failure Mode and Effect Analysis to identify potential single failure points (SFP's) of the test configurations which could have jeopardized crew or test personnel safety or caused premature test termination. Potential SFP's were eliminated where possible and special emphasis was placed on the review and evaluation of the remaining SFP's. MMC assisted with the MDA portion of the FMEA. This report was reviewed by Airlock Safety with particular consideration given to Category I (safety) classifications. This report was also presented to the ORI Committee for evaluation.

Airlock altitude chamber tests were monitored by Airlock Safety and the Life Science Group. A trained rescue team was constantly on station to assist the flight crew during critical test phases or in cases where Crew Safety was

jeopardized if serious test equipment malfunctions occurred. A medical monitoring panel was in operation so that the physical condition of the flight crew was continuously monitored. Both Airlock Safety and Life Science representatives were on the communications network.

4.1.3 Mission Performance

Mission reports indicate that no conditions developed in the Airlock that endangered the health or safety of the flight crew during the Skylab mission.

4.2 INDUSTRIAL SAFETY

4.2.1 Motivation and Control

MDC Safety and Medical Department conducted a general safety motivation program by scheduled meetings which Industrial Safety representatives attended. Potential safety problems in each representative's area and their solutions were discussed and possible motivations were formulated to prevent problem recurrence. These safety representatives were concerned principally with operations with facilities hardware and industrial machinery. General safety posters and bulletins were released to remind personnel of standard safety practices. Airlock Safety attended many motivation meetings and supported these efforts to stimulate Airlock personnel awareness that the Skylab Program was a manned program. The Airlock safety effort was in cooperation with the MSFC Manned Awareness Program and was initiated and controlled by upper level management of MDAC Product Assurance. Poster ideas were generated by Airlock Safety. These posters presented a reminder of the importance of each technician's effort to the safety of the crew. The posters were placed in all areas where Airlock assembly and testing were accomplished. In addition, posters received from MSFC were posted in appropriate locations. A committee was formed to review employees who demonstrated outstanding safety records. The committee selected the most proficient and motivated employee of those recommended, to participate in the Manned Awareness Program honor of witnessing the launch of Skylab.

Informal safety audits of Airlock activities from design through test were conducted periodically by the Airlock Systems Safety Officer to determine

personnel awareness of safety requirements and guidelines released for implementation and guidance. The audits also included efforts to insure that proper safety motivation existed. Formal safety audits were conducted by MSFC Safety, Reliability and Quality Audit teams and by a NASA Headquarters assigned Safety Review Committee.

Accident/Incident Reports - Early in the Airlock Program, MDAC-E Airlock Program Management established a requirement for all Accidents/Incidents to be reported to the Airlock Safety Officer; the Safety Officer investigated each incident. In each case the conditions that preceded the incident/accident were evaluated and recommended corrective action was forwarded to assembly and test supervision to prevent a recurrence. Each incident/accident report with Safety investigation results and corrective action was presented and discussed with the NASA Plant Resident Manager during monthly MDAC-E/NASA Meetings. In addition, the reportable accident was reported on NASA Form 666 to the MSFC Safety Manager.

4.2.2 Safety Training

Several phases of training were accomplished to prepare for the Altitude Chamber Test. All key test personnel, altitude chamber operators and rescue team members were trained and certified in accordance with the Airlock Systems Safety Plan. Many practice runs were made to accomplish on-the-job training for altitude chamber operators. The rescue team members were given extensive classroom training as well as practice in the chamber facilities. MDC Report E0551, "Selection, Training and Certification for Personnel involved in Airlock Chamber Testing at the McDonnell Douglas Corporation Facilities in St. Louis," was prepared and released by the Life Science Group. This report describes the training that was accomplished for the Airlock Test Crew.

Airlock Safety participated in the preparation of Airlock training TV films. One safety film dealt with the necessary care in handling and installation of ordnance items for the ATM Deployment Assembly. This and other training films were made for presentation to Airlock technical groups and NASA personnel.

4.3 CONCLUSIONS AND RECOMMENDATIONS

Guidelines instilled in design groups through the normal safety program provided an inherently safe foundation for Airlock flight and ground hardware design. Special emphasis applied through the Manned Awareness Program enhanced this basis, resulting in an exceptionally good program from the standpoint of flight and ground crew safety.

It was concluded that the provisions of the Airlock Systems Safety Plan were properly implemented. The safety record indicates that the Safety Plan and other written safety documents were satisfactory guidance for the safe conduct of the program.

It was also concluded that the Safety Motivation and Manned Awareness Program as implemented was highly effective. This was apparent from the attitude and proper effort exerted by all program personnel.

It is recommended that a document similar to the Skylab Systems Safety Checklist be developed for use in all future designs of spacecraft to assist in incorporation of safety early in design.

SECTION 5 TEST PHILOSOPHY

5.1 TEST REQUIREMENTS

Airlock testing requirements expanded significantly through the years, consistent with program growth from its inception in 1965 as an "Experiment" to the final sophisticated vehicle launched in 1973. The following brief historical summary provides rationale for the changing test requirements philosophy.

5.1.1 Test Requirements Background

When the initial "workshop type" mission was conceived in 1965 as Spent Stage Experiment Support Module (SSESM), the development and qualification test program was most insignificant in scope. Since all components on the vehicle were basically "off-the-shelf" Gemini hardware, only a small number of components and assemblies required additional qualification testing. The original proposal viewed the mission as an experiment, and an "open ended" testing philosophy was applied in the literal sense. The philosophy used in the formulation of early Airlock testing requirements was that the primary mission for which all systems would be qualified would be of fourteen days duration, and that additional orbital mission time beyond the first 14 days would be flown so long as there was no problem with the basic systems and sufficient expendables were available. The design approach was aimed at insuring that no Airlock system would preclude attainment of the desired 14-day mission objective, but the test program would only explore capability beyond the 14 days in a relatively cursory manner. Flight hardware acceptance testing at the component, module and full vehicle level was planned to be performed in the conventional manner established during the Gemini program but in greatly reduced scope due to the simplified systems in the early Airlock.

In early 1967, Airlock began to evolve as the nerve center of the Environmental/Thermal Control, Electrical and Communications Systems in an expanding Skylab vehicle. In much the same way as the configuration of the Airlock itself changed from a simple minimum-cost vehicle to the central core of a cluster of sophisticated space vehicles, so did the test program approach vary from the original minimum-cost, high reliance on good judgement type approach, to a comprehensive approach more typical of contemporary space programs. Nevertheless, the program verification approach remained consistent with the concept of

extensive use of system engineering analysis and previous test results in identifying the minimum supplemental tests necessary to assure confidence in achieving primary mission objectives and preserving crew safety.

With the issuance by NASA in 1967 of the Apollo Applications Test Requirements (AATR) Document NHB 8080.3, it was obvious that a systematic analysis of Airlock performance/design requirements was desirable in order to formally define a new baseline test program. Recognizing this need, NASA, in November 1967, authorized MDAC-E to proceed with a test program review trade study. Figure 5-1 defines the trade study methodology used to plot Figure 5-2, which illustrates how the optimum delta test program (C' plan) was selected as a new baseline. Test packages were rated on a numerical grading system. The test plans ranged in magnitude from plan A, which advocated diverting U1 to become a test vehicle for a complete AM/MDA thermal vacuum test, along with additional module level development tests, to plan E, which consisted of no change to the original test plan. When the "increased value" was plotted against test cost it was apparent that the C' plan was the cost effective "knee" of the curve. The major tests established by the C' plan were as follows:

- ECS/TCS Endurance Test (ET-1)
- Electrical Power System Development Test (DT-10)
- Radiator Panel Heat Transfer Test
- Condensate Dump Test
- Equipment Sound Level Measurement Tests
- CRDU/DCS RFI and Interface Test
- Audio/Caution and Warning System Compatibility
- Apollo Audio Center and Voice System Compatibility

The above testing effort was defined in CCP 33. Component level endurance tests verifying hardware for full mission life requirements were included in the same change proposal. Subsequent ECP's/CCP's defined additional test program impact associated with each new hardware change.

5.1.2 Verification Process

The verification process for the Airlock Module design was an optimal combination of analyses and/or testing which demonstrated the capability of the flight systems to perform the mission as described by the Airlock Performance/Configuration Specification, MDC Report E946, and the Payload Shroud Performance/Configuration

SUBSYSTEM ANALYSIS

- IDENTIFY AIRLOCK SUBSYSTEM PERFORMANCE REQUIREMENTS BY SUBSYSTEM FUNCTION.
- TRANSLATE DESIGN/PERFORMANCE REQUIREMENTS INTO TEST REQUIREMENTS BY ANALYSIS.
- CONDUCT TRADE-OFF STUDIES OF A NUMBER OF ATTRACTIVE SUBSYSTEM TEST APPROACHES IN ORDER TO QUANTITATIVELY SELECT THE OPTIMUM TEST PROGRAM.
- PLOT INCREASED TEST VALUE VS. THE INCREASED TEST COST TO DETERMINE THE MOST COST-EFFECTIVE PLAN.
- RECOMMEND NEW SUBSYSTEM TEST APPROACH.
- COMPARE THE RECOMMENDED TEST PLAN TO THE CONTRACT BASELINE TEST PLAN.
- IDENTIFY DELTA SUBSYSTEM TEST PROGRAM COST AND SCHEDULE AFFECT.

EQUIPMENT LEVEL EVALUATION

- CATEGORIZE EQUIPMENT AS CATEGORY 1, 2 OR 3 BASED ON EQUIPMENT FUNCTIONAL USAGE.
- AFTER CATEGORY SELECTION, ESTABLISH ANALYSIS/TEST APPROACH BASED ON AATR (NHB 8080.3) QUALIFICATION REQUIREMENTS.
- ANALYZE PREVIOUS QUALIFICATION TEST HISTORY AND DEMONSTRATED LIFE TESTING TO DETERMINE ACCEPTABILITY OF EQUIPMENT FROM OTHER PROGRAMS.
- FOR NEW EQUIPMENT, COMPARE NEW AATR QUALIFICATION CRITERIA TO THE AIRLOCK BASELINE TEST PLAN.
- IDENTIFY RECOMMENDED DELTA EQUIPMENT TEST AND ASSOCIATED COST REQUIREMENTS.

FIGURE 5-1 TEST PROGRAM TRADE STUDY

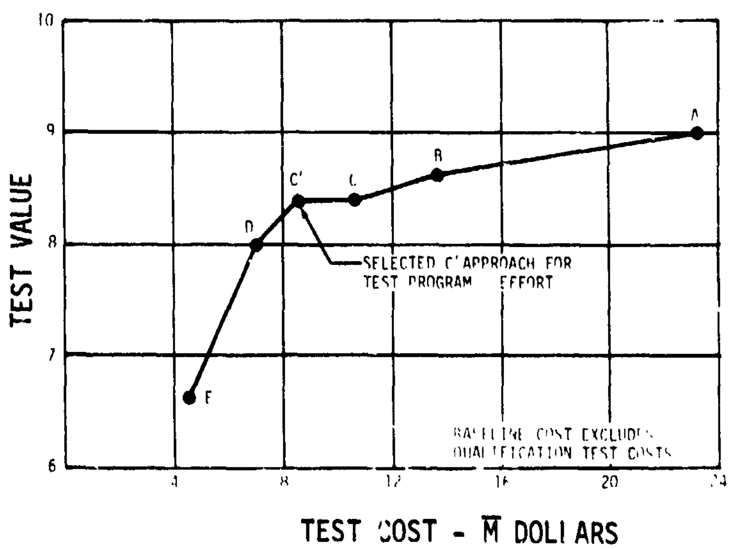


FIGURE 5-2 AIRLOCK TEST PROGRAM TRADE STUDY RESULTS

Specification, MDC Report E0047. Flight hardware was verified by acceptance testing at component, assembly and system levels as defined in the Airlock Acceptance Test Plan, MDC Report E914. Development and qualification testing was defined in MDC Report F767. Figure 5-3 shows the relationship of test planning and statusing documentation.

Systems engineering analysis concepts were applied to translate performance and design requirements into requirements for test. In translating performance and design requirements into test requirements, MDAC-E conducted analyses within the overall framework of the open-ended flight operation concept. In recognition of the applicability of test and flight data on previously flown equipment now being used on Airlock, the systems engineering analysis conducted on these equipments derived the minimum testing necessary to supplement existing data. This testing was designed to complement the analysis so as to provide complete Skylab mission verification at minimum expenditures of program resources.

Additionally, the verification process placed heavy emphasis on the evaluation and use of existing data generated during prior tests and flight usage experience on equipment similar to Airlock equipment. A historical test data search was made of equipment which was similar to that designated for use on the Airlock Module. A direct comparison of configuration and performance requirements to equipment capability was made. Equipment failures experienced during test programs and operational usage were evaluated to establish additional supporting justification and were documented to support verification requirements in the Airlock Acceptability Review, MDC Report G499.

The process employed in the translation of performance and design requirements into requirements for additional testing was as follows:

- Defined the equipment duty cycle.
- Defined the environment in which the equipment must work.
- Assembled all pertinent data available with respect to equipment capability.
- Reviewed duty cycle and environments required in the light of available data.

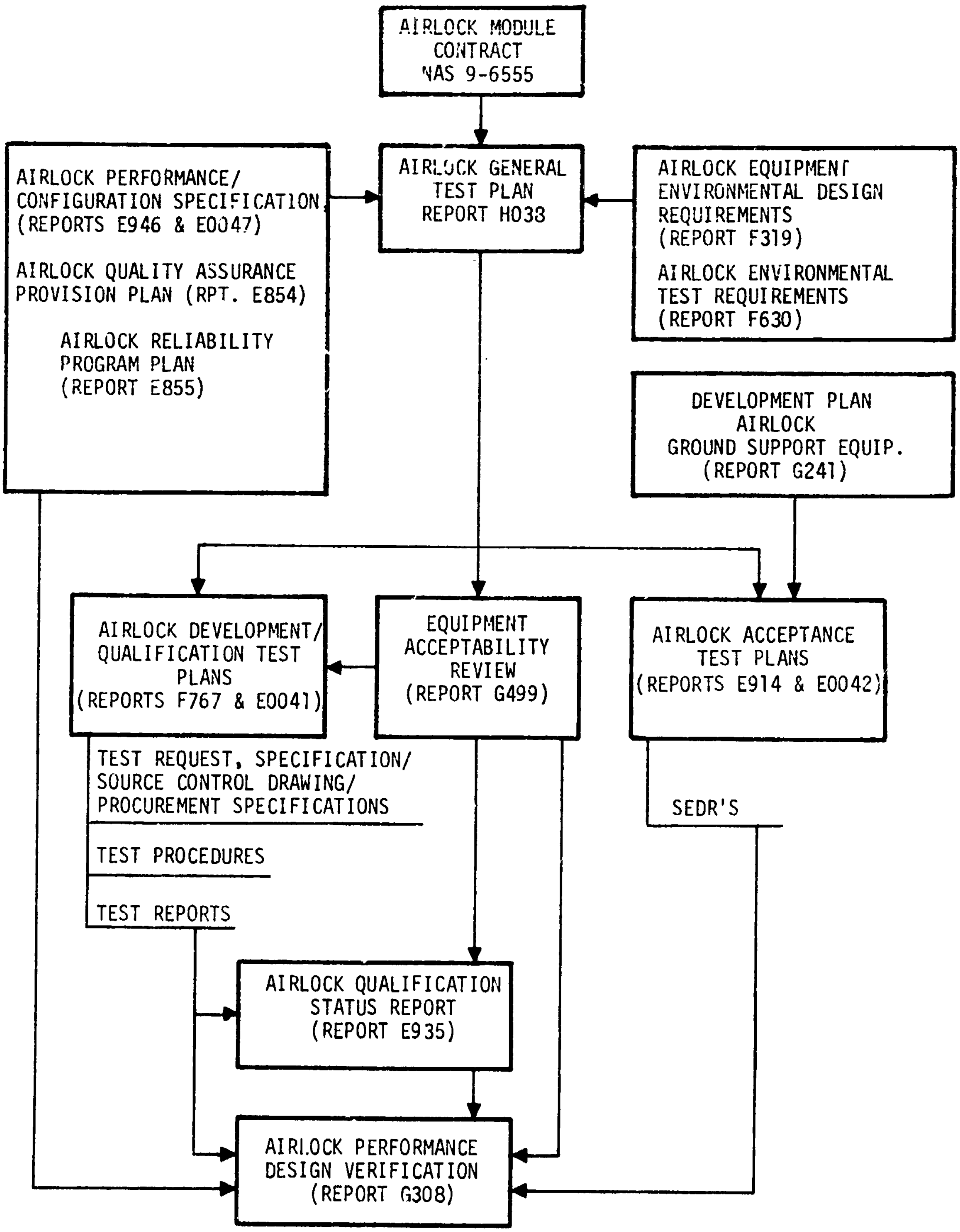


FIGURE 5-3 TEST PROGRAM DOCUMENTATION

- Where necessary, established and performed that additional testing determined to be necessary to give assurance of equipment capability and/or changed a problem constraint such as duty cycle, environment, etc., by redesign or mission adjustment.
- Documented the final acceptability disposition for all equipment.
- Obtained necessary NASA approval by including an Airlock Acceptability Review between NASA and MDAC-E. Results of those meetings were documented in MDC Report G499.

5.1.3 Launch Site Test Requirements

Launch site test requirements were specified in Report MDC E0122, Test and Checkout Requirements, Specification and Criteria at KSC for the AM/MDA. Prelaunch tests were established to verify compliance with design requirements. The Test and Checkout Plan, KS2001, defined the tests to be performed at the launch site to comply with the specified requirements.

5.2 VERIFICATION TEST PHILOSOPHY

Verification testing was performed at all levels, from the component to the full vehicle level. Appendix B, Testing Required to Qualify Airlock Equipment, from MDC Report F767, Development and Qualification Test Plan, provides an overview of the total components verified for Skylab, by system; the matrix illustrates facilities and the relationship of component level verification to higher level assembly verification (designated M). Appendix C, provides a listing, by Test Request (TR) Number, of the development and/or qualification testing performed by MDAC-E in-house facilities during the Airlock Program. The philosophy utilized for testing at the various levels is described in the following paragraphs.

5.2.1 Qualification Testing

Qualification tests were performed on each component of Airlock flight systems where analysis indicated that sufficient information was not available by which the design and performance requirements could be verified.

Environmental verification was generally performed at the component level. Equipment qualification testing was varied depending upon the criticality relative to crew safety and mission objectives. The process for qualification program definition is depicted in Figure 5-4.

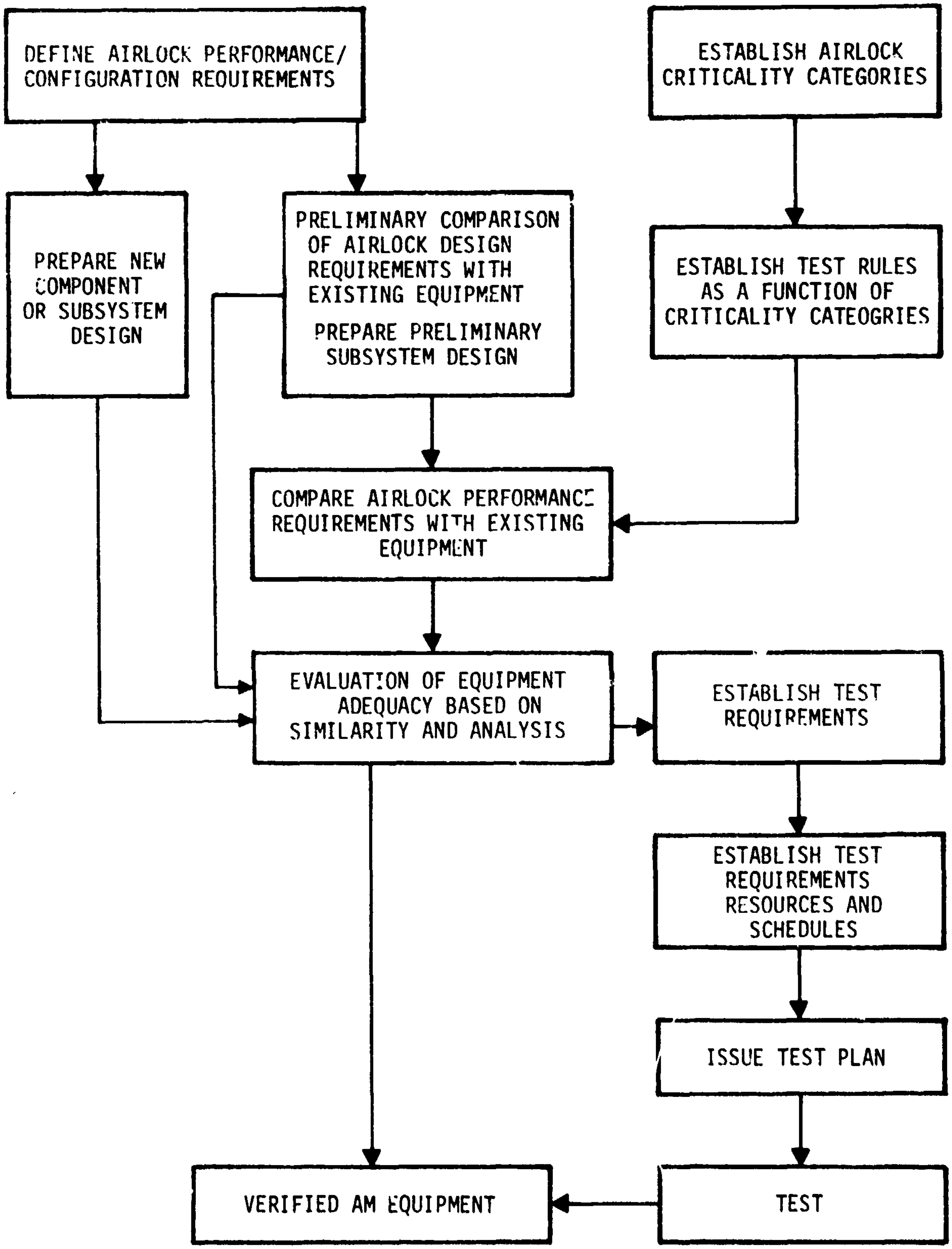


FIGURE 5-4 PROCESS FOR QUALIFICATION PROGRAM DEFINITION

Qualification of all Airlock equipment was established by its criticality category as defined in Appendix B of Exhibit A to the Airlock contract which in turn defined the extent of the test effort (See Figures 5-5 and 5-6).

Category 1 - Equipment in those systems whose functional failure could adversely affect crew safety. This includes potential catastrophic failures in space, as well as all failures which would preclude safe recovery of the crew in a planned or contingency recovery area. (Assume 12 hours between failure and landing.)

Category 2 - Equipment in those systems whose functional failure could preclude primary mission objectives accomplishment.

Category 3 - All equipment excluded from Categories 1 and 2.

*As delineated in Appendix B of Exhibit A to Contract NAS9-6555.

FIGURE 5-5 FLIGHT HARDWARE CRITICALITY CATEGORY*

HARDWARE CRITICALITY CATEGORY	NUMBER OF TEST ARTICLES
1	2
2	1 PLUS 1 SPARE*
3	1 PLUS 1 SPARE*

*Spare tested on as needed basis

FIGURE 5-6 SUGGESTED NUMBER OF QUALIFICATION TEST ARTICLES

5.2.2 Endurance Testing

When the Airlock test program was expanded in 1968 to include endurance verification for the full mission duration, this testing was planned to be performed at the highest practical level. The majority of components requiring simulated mission endurance testing were verified in the ECS/TCS Module Test (ET-1). Figure 5-7 defines the simulated ground and mission duty cycles as established by the Airlock General Test Plan, MDC Report H038 (Table 5-4)

DEFINITION OF GROUND OPERATION CYCLE AND SIMULATED MISSION DUTY CYCLE
GROUND OPERATIONAL CYCLE: Test levels for ground operations must be consistent with the anticipated operation and handling requirements for vendor acceptance, preinstallation acceptance, ground operational checkout and prelaunch testing. Test levels and durations must be determined for each component or subassembly to establish verification requirements.
SIMULATED MISSION DUTY CYCLE: In all tests which define operating requirements as multiples of "a simulated mission duty cycle" the operating times or cycles for the equipment are derived from the applicable environmental design reference mission. For test purposes, the time duration of each phase represents the worst condition for any planned mission. Duty cycles, in general, will be conducted at nominal mission environmental levels. Environments, as applicable, are applied to combination (as feasible) at nominal mission conditions for actual mission times. Performance will be demonstrated before and after environmental exposure as appropriate to actual use conditions.

FIGURE 5-7 ENDURANCE TESTING

5.2.3 Subsystem Development Testing

Several subsystem level tests were performed at MDAC-E to verify higher level assemblies at anticipated environmental conditions and in many cases to off-nominal extremes. While these tests were called development tests rather than qualification, the test specimens were generally highly sophisticated assemblies of previously qualified components and subassemblies. The tests provided a relatively early demonstration of system interactions and interfaces; and, thereby provided high level subsystem performance data in time to allow for possible modification of flight hardware. Some of the more significant tests in this category were the following:

- Airlock internal hatch and hatch mechanism.
- ATM/DA rigidizing system development.
- ATM/DA deployment demonstration.
- Digital Command System and Command Relay Driver Unit interface development.
- Audio system/Caution and Warning System compatibility development.
- Apollo Audio Center and Voice system compatibility development.
- Electrical Power System battery module performance and thermal vacuum test.
- Life cycling tests of nickel-cadmium batteries.
- Condensate dump system thermal performance.
- EVA/IVA water cooling subsystem development.
- Water servicing development test for condensing heat exchanger.
- O_2/N_2 two gas control system development.
- Suit/battery cooling module thermal development.

5.2.4 Flight Hardware Testing

The following general ground rules were followed in the preparation of all test plans and procedures involving flight hardware.

A. During and after performance of test sequences, all parameters were evaluated against performance specifications. All systems were checked to demonstrate performance within specification limits in order to be considered flightworthy. No system or subsystem encountering a malfunction was considered flightworthy until the malfunction was corrected or satisfactorily explained and accepted. All parameters exhibiting marginal performance were evaluated against previous test results.

B. Functional testing, including support equipment, did not introduce any input, switching, pseudo operation, loading, or other adverse effect which might compromise equipment performance or previous test results. The tests did not degrade flight performance.

C. Functional tests were performed after the equipment was in flight ready configuration and was appropriately reverified if the equipment or overall configuration was subsequently changed, modified, or expanded. (Flight ready configuration existed only when flightworthy equipment was installed.)

D. All equipment interfaces were functionally tested. Equipment removal for test purposes was held to a minimum.

E. Duplication of testing was minimized.

F. All equipment operating times/cycles for test purposes was minimized and was recorded for time/cycle critical components.

G. The test complex, with required GSE, was validated prior to mate with the AM, MDA, DA, or FAS. The verification and acceptance of GSE was described in MDC Report G241, Development Plan-Airlock Ground Support Equipment.

H. All tests were conducted in conformance with approved process specifications, operating procedures, safety requirements, and conditions as specified in MDC Report G671 - Airlock Safety Plan.

Simulators were used to a large degree in the early stages of systems tests; these were designed to simulate inputs and responses of those Skylab modules, such as the MDA, CSM and OWS, not present for the test activity. As the test program progressed, the use of simulators decreased. For example, after AM/MDA mate, the MDA simulator was no longer used. These simulators allowed full systems checkout with a high degree of realism and served to provide confidence in complete systems performance during the launch site activity.

The simulators utilized were not of the level one type, i.e., nearly exact reproductions of those systems they simulated. However, the level of simulation was adequate for the objective of obtaining confidence in orbital vehicle systems performance.

5.2.4.1 Planning of the Overall Test Flow

Conformance to design requirements was verified through a progressive building-block approach to testing which had been employed by MDAC-E with success on projects such as Mercury and Gemini. This activity included component level bench testing of selected functional hardware, testing of selected subassemblies consisting of several functional components, individual systems testing of the Airlock module systems, combined Airlock module systems testing, and integrated systems and module (MDA-CSM-LV) testing. During each phase of the test activity, the general philosophy of solving any problems and successfully retesting to demonstrate adequate performance prior to proceeding to the next testing phase was followed. Where, due to hardware availability or other unique problems, this philosophy could not be followed, suitable work-around plans were developed and executed to assure complete and adequate testing of each system/subsystem/component.

Figure 5-8 is a simplified representation of the overall test flow commencing with component hardware delivery to the development center (MDAC-E) through launch of Skylab I. The program was highly successful in attainment of both of its objectives, i.e., in delivery to the launch site of a spacecraft with satisfactorily operating systems, and launch of a problem-free orbital vehicle. Test flow planning for those KSC activities to be accomplished subsequent to delivery of the spacecraft and support hardware to the launch site was initiated well in advance of the hardware delivery. This planning activity was accomplished under separate contract by MDAC-Florida Test Center (FTC) personnel in conjunction with NASA-KSC personnel and was based on requirements established by a working group from NASA-MSFC and MDAC-E.

Overall test flow planning commenced early in the program. The result of this planning activity for the MDAC-E facility was published in the Airlock Acceptance Test Plan, MDC Report E914, originally released 1 November 1967. This was a dynamic report, outlining each test to be performed, and was periodically revised to reflect program changes as they developed. The test plan and revisions were submitted to appropriate NASA elements for review and comment. The test flow at MDAC-E as presented in the final Airlock Acceptance Test Plan is shown in Figure 5-9.

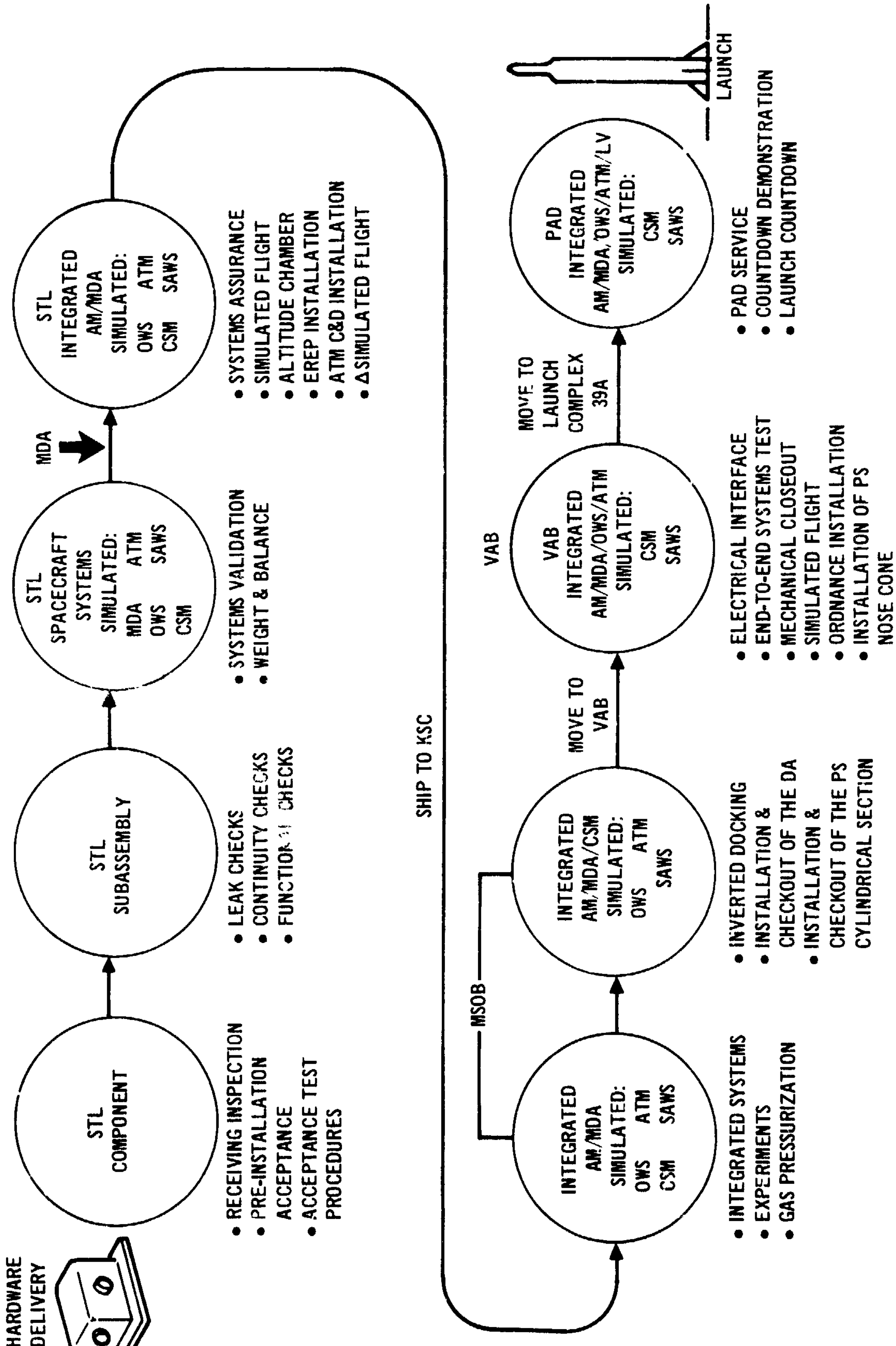


FIGURE 5-8 OVERALL PLANNED TEST FLOW

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

FIGURE 5-9 PLANNED TEST FLOW AT MDAC-E

The test flow consisted of two phases. The Phase I testing included all tests performed on the spacecraft or major assemblies thereof during the manufacturing buildup activity. These tests consisted of all subassembly tests and preliminary leakage tests of installed plumbing and were designed to reduce test problems and hardware removal during the Phase II test activity. The less complex or critical testing in Phase I (those procedures with an M prefix, e.g., D3-M14) was performed by manufacturing personnel. Other tests in Phase I were performed by ATLO with assistance from Manufacturing personnel. In all cases, the procedures were prepared in conjunction with technical data specialists and were approved by NASA representatives. The Phase II test activity consisted of all test activity performed on the assembled spacecraft. This phase commenced when manufacturing buildup of the spacecraft had essentially been completed and the assembled spacecraft was turned over to ATLO.

The testing planned on the backup flight hardware (U2) followed a flow similar to that for U1 up to the point of going into the altitude chamber after completion of the simulated flight test. The EREP experiments were removed and sent to MMC, Denver and along with the AM/MDA were programmed to be maintained in a simulated flight configuration to support the U1 mission.

5.2.4.2 Component/Subassembly Testing

Component testing was accomplished prior to installation of the majority of functional components onto their next higher level assembly (subassembly, spacecraft). Selection of components requiring preinstallation acceptance (PIA) testing was accomplished early in the program, and was based upon the following ground rules. All new-design or redesigned functional components from prior programs were PIA tested. Functional components of an existing design were PIA tested on a selective basis dependent upon general component factors, e.g., previous operational history, vendor, impact on vehicle system if component required removal and reinstallation due to malfunction of component, and relative complexity of removal of component from the vehicle system.

Certain subassemblies or modules such as electronics modules, molecular sieves, radiator panels, and pump modules, were designated as requiring test prior to installation of the subassembly onto the major spacecraft structure.

Those were selected on the basis of their complexity, the complexity of the installation, degree of installed test possible, accessibility after installation and/or possible schedule impact of removal for repair/replacement of hardware should a problem develop after installation.

5.2.4.3 Spacecraft Systems Test

The AM systems were tested both as individual systems and in combined systems operational mode, prior to mate with the MDA. This phase of testing activity consisted of checking out each system in detail on an individual basis with parallel testing where possible and finally operating the systems in a combined mode to determine any unexpected system operational problems. Similar testing was performed on the MDA at Denver by the Martin Marietta Corporation prior to shipment of the MDA to MDAC-E and its subsequent mate to the AM. This activity established confidence in the AM systems to perform as a system and provide interface interaction with the complete AM.

5.2.4.4 Integrated AM/MDA Testing

Integrated AM/MDA System Testing was accomplished after the mate of the MDA to the AM. Testing followed the general philosophy and ground rules given in Section 5.2.4.1 above. As the test program progressed, particular emphasis was applied to the ground rules especially concerning the control of wire bundle disconnections and systems hardware flightworthiness. The EMC aspects of the test required the use of break-out cables and care was taken to assure that the procedure called for reconnection and revalidation of the flight connectors. The simulated flight runs which followed the EMC activity had, as their objective, to demonstrate the satisfactory performance of spacecraft systems on a system level with the systems in flight configuration when operated in planned flight modes and sequences.

5.2.4.5 Documentation - Flight Hardware

The technical Data Department prepared documentation to support all testing of Airlock/MDA flight hardware and Ground Support Equipment (GSE) at MDAC-E. Figure 5-10 presents a summary of the types and quantities of data provided. The data was generally produced in preliminary (pink copy) form and distributed to all concerned elements of ATLO, Design Engineering, Manufacturing, Quality Control, and NASA for review. Comments were then incorporated and the final (white) copy was produced and routed for approval. Additionally, all major test documents were reviewed in detail at formal meetings prior to release. Figure 5-11 shows a typical sequence of events for the major documents.

TYPE	NUMBER OF SEDR'S	TOTAL PAGES
MISCELLANEOUS	9	786
PIA	8	6,140
SST (U1)	112	20,289
SST (U2)	60	6,000
ATP	82	4,195
RTP	132	4,067
O&S	76	5,344
PCN (NON-INCORPORATIVE)	---	5,560
TOTAL	478	52,381

*DOCUMENTATION FOR U2 UTILIZED THE U1 DOCUMENTS WITH APPROPRIATE CHANGES.

FIGURE 5-10 TOTAL ACCEPTANCE TEST PUBLICATIONS (U-1 AND U-2)*

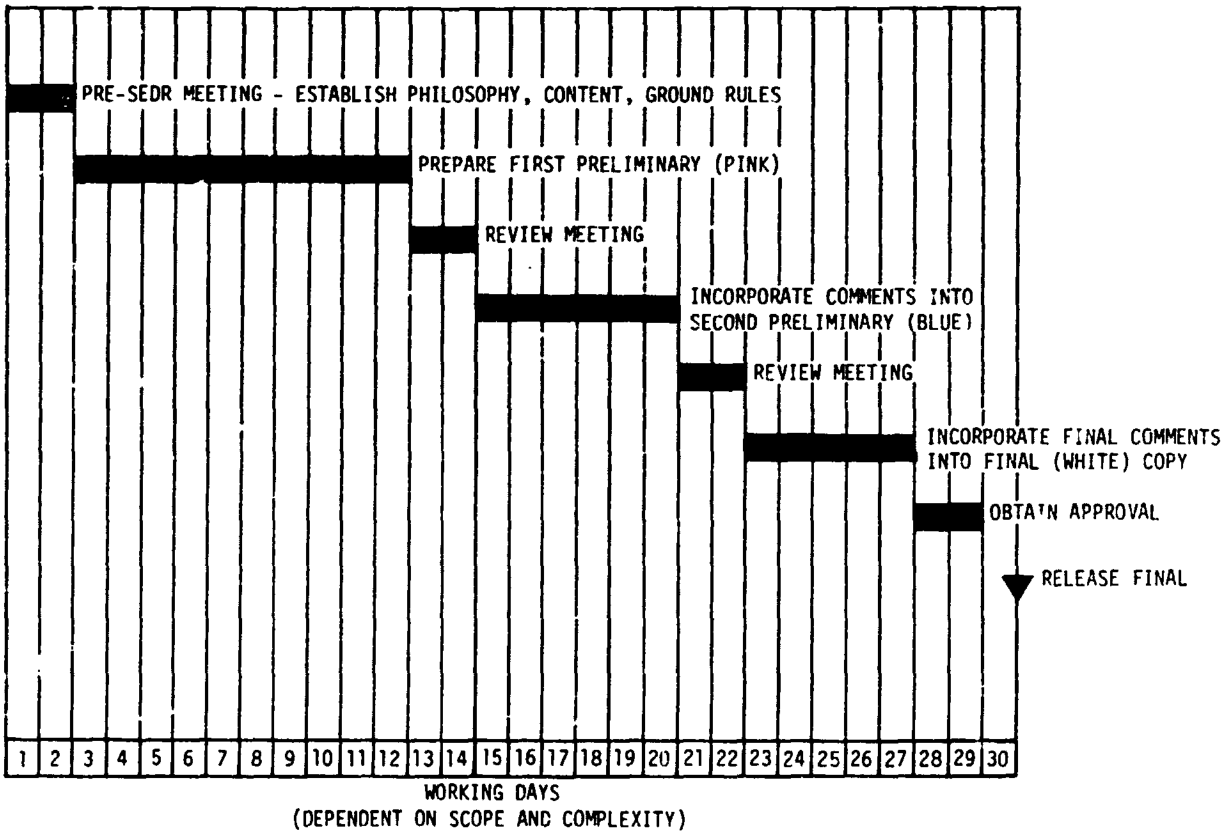


FIGURE 5-11 TYPICAL MAJOR TEST DOCUMENT PREPARATION SEQUENCE

5.2.4.5.1 Test Requirements

Test requirements were provided to the Technical Data Department by Engineering personnel. These requirements were based upon the Acceptance Test Plan, Report E914, and other documentation such as:

- System Component Specifications.
- Interface Control Document (ICD) requirements.
- Airlock Performance/Configuration Specification, Report E946.
- Design Drawings.
- Airlock General Test Plan, Report H038.
- Airlock Performance/Design Verification Report.
- MDA Systems Test and Checkout Requirements, Report ED-2002-2020 (MMC).

For the major test documents, these requirements were compiled into another informal document to assist the Technical Data Department in preparation of the procedure and to assist in review of the document. This was done on an informal basis at the request of the NASA Quality personnel. These "Test Data Requirements Sheets" were prepared by ATLO Engineering and compiled and distributed by the Technical Data Department.

5.2.4.5.2 Types of Data Provided

Figures 5-12 and 5-13 show the acceptance test-related documentation tree and a generalized test flow commencing at the component or bench level and continuing through the subassembly or module level testing which was done on a selective basis, the individual installed systems/subsystems testing, and the integrated systems testing. These two figures show the relationship of the various types of flight hardware documentation provided.

A. Miscellaneous Documentation - A total of nine test-related documents of a miscellaneous or support nature were provided. These included such documents as the Acceptance Test Plan, MDC Report E914, and Test and Checkout Requirements, Specification and Criteria (TCRSD) MDC Report E0122 which baselined test requirements to be accomplished at the launch site, and the PIA Summary, SEDR D3-2.

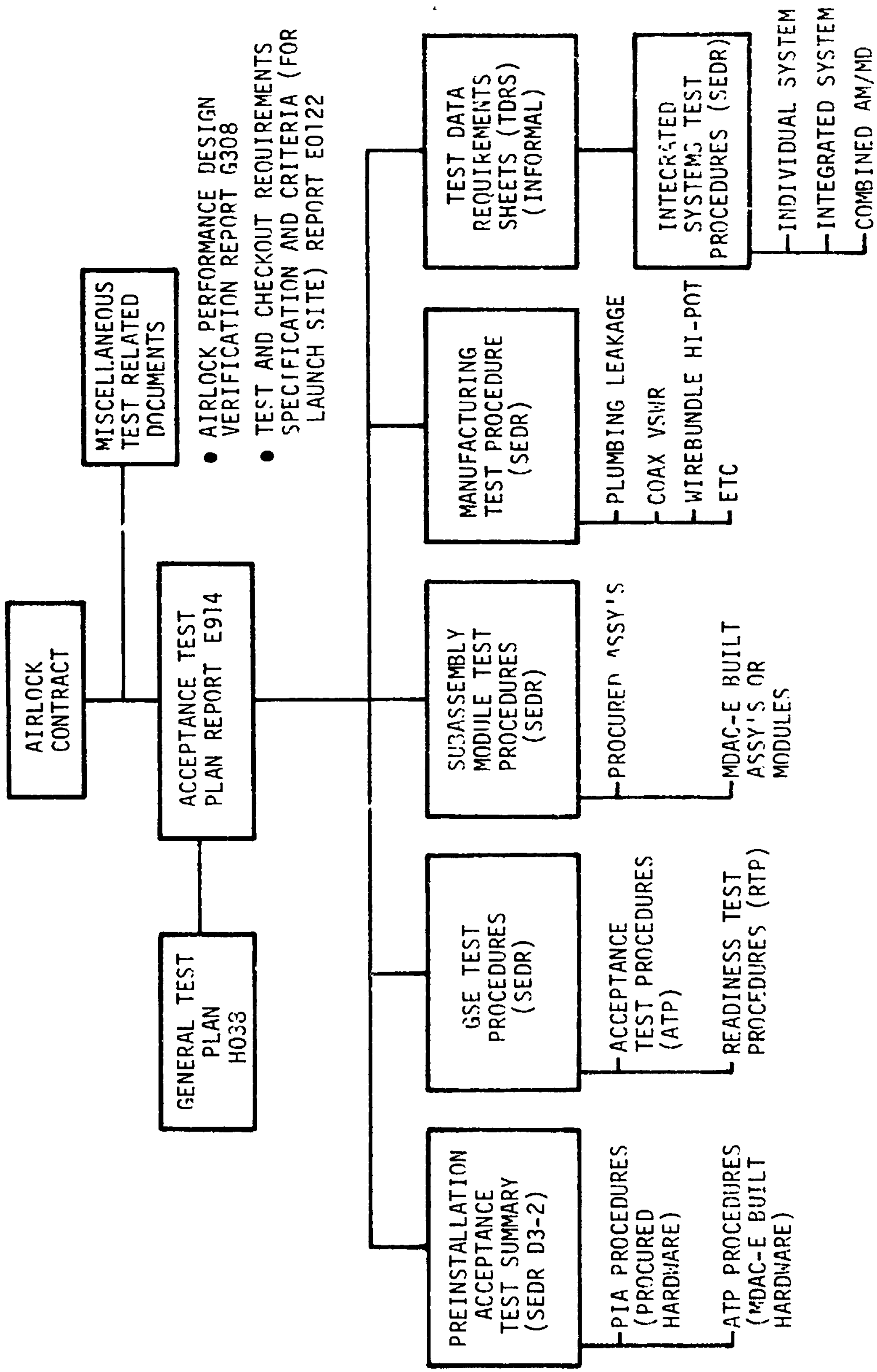


FIGURE 5-12 ACCEPTANCE TEST DOCUMENTATION TREE

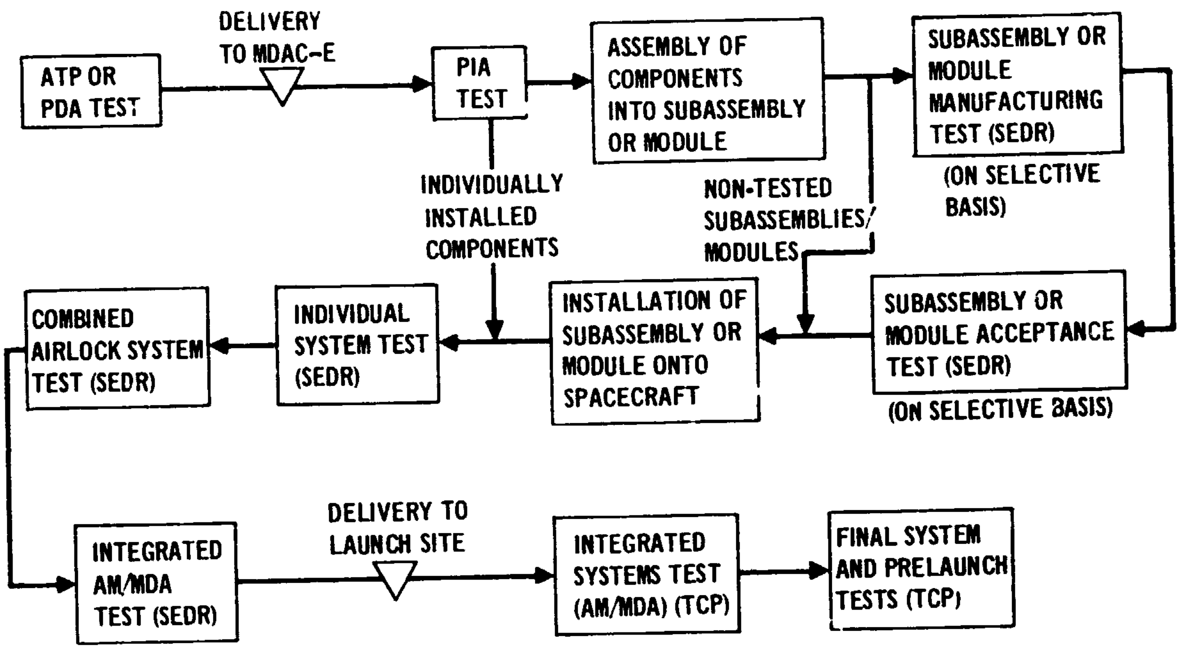


FIGURE 5-13 GENERALIZED OVERALL TEST FLOW

B. Component (PIA) Test Procedures - Eight documents, which provided detailed test procedures for the component-level Preinstallation Acceptance (PIA) testing of individual flight components, were produced. These were utilized for U1, U2, spare, and test hardware acceptance. Those components to be subjected to this type of test were delineated in SEDR D3-2. In a few cases, the requirement to perform this testing was waived by processing a formal waiver request through the required approval cycle, which included NASA engineering and Quality Control personnel. This waiver contained justifying rationale considering component history and was usually predicated upon MDAC-E engineering and/or Quality Control personnel witnessing similar tests at the supplier's plant.

C. GSE Test Procedures - Procedures were prepared for the acceptance testing of newly built or extensively modified residual support equipment and for performing functional tests of the GSE prior to usage. Operation and service manuals for the GSE were provided where required.

D. Flight Hardware Acceptance Test Procedures - Documents produced for use on the U1 spacecraft included subassembly or module tests, as well as the individual and integrated systems tests. Documents in support of testing performed on the backup flight hardware (U2) were produced by utilizing the U1 documentation with appropriate changes and updates to reflect the configuration and scope of testing to be performed as well as to incorporate any required changes.

E. Manufacturing Test Procedures - Flight Hardware Procedures were prepared to support the manufacturing process and were known as manufacturing test procedures. These tests were performed to validate various portions of the manufacturing process such as the hi-pot of relay panels and leakage validation of installed plumbing while still accessible.

5.3 U1 VERIFICATION TESTING

5.3.1 Integrated Structural Testing

MDAC-E participated with NASA in a static and dynamic test program which provided experimental test data necessary to verify the structural adequacy of the AM/MDA and the appropriate interface joints. The following ground rules were the bases for the combined structural test plan:

A. MDAC-E delivered to NASA a Structural Test Article fabricated from appropriate production structure and designated as STA-1 for the static test configuration and as STA-3 for the dynamic test configuration.

B. Static testing was performed at the MSFC structural test facility; and after the specimen was modified to the STA-3 configuration, dynamic testing was performed at the JSC vibroacoustic test facility. Static testing was performed during the period from 11 May 1970 to 20 June 1970. Dynamic testing started on 8 September 1971 and was completed on 23 June 1972.

C. The FAS and DA were designed to a factor of safety of 3.0 for manned loading conditions and 2.0 for unmanned. Strength analysis utilizing finite element computer programming was performed to show structural capability. Based on these large factors of safety and the detailed strength analysis, static testing was not required to verify the structural adequacy.

All major structural components of the AM, including the FAS and DA, were subjected to vibroacoustic testing and successfully passed these environments.

5.3.1.1 AM/MDA Static Test Program

The AM static test article (AM STA-1) was delivered to MSFC in May 1969 for static testing to Saturn IB launch and ascent loads and was structurally representative of the AM "wet" workshop configuration. In August of 1969 the Skylab program was changed to the "dry" workshop configuration, which necessitated several changes to both the AM configuration and launch and ascent loads. Because sufficient similarity existed between AM STA-1 and the AM flight articles, it was jointly agreed by MSFC and MDAC-E that acceptable verification of the "dry" workshop AM U1 flight article could be accomplished by continuing with the planned testing of the STA-1 "wet" workshop AM structure supplemented by suitable analyses.

The testing on STA-1 was successful and supplemental strength analyses verified the structural adequacy of the U1 flight article.

Description of STA-1, differences between STA-1 and U1, results of tests and the results of the strength analyses is presented in MDC Report E0517, "Verification of U-1 Launch and Ascent Structural Capabilities Based on Evaluation of STA-1 Static Test Results," dated 18 January 1972.

A. Test Objectives - To demonstrate the structural capability of the combined AM/MDA vehicle and their interfaces to sustain ultimate loads associated with the critical design conditions. Test conditions included:

(1) Internal Pressurization and Leakage Tests

- Overall AM/MDA pressurization.
- Maximum tunnel compression load.

(2) Critical Liftoff Conditions

(3) Maximum Acceleration Conditions

B. Test Results - Testing requirements were documented in MDC Report G079, dated 8 May 1970. Test results are summarized in MSFC Report IN-ASTN-TMS-71-7, dated May 1971.

5.3.1.2 Vibroacoustic Testing of the Skylab Payload Assembly

The dynamic testing of the Skylab Program Payload Assembly Test (PAT) article consisted of an acoustic and a vibration test. The acoustic test conducted in the reverberant acoustic test chamber exposed the PAT article to the maximum expected liftoff and boost acoustic environments. The vibration test was in two parts, a Vehicle Dynamics Test (VDT) and a Modal Survey Test (MST). The VDT simulated the low frequency environment resulting from the launch vehicle cutoff and separation transients and consisted of a sinusoidal sweep and decaying sinusoidal transients applied along the vehicle longitudinal axis. The MST was performed to obtain the characteristic vibrational frequencies, mode shapes, damping coefficients, and generalized masses of the normal modes. The PAT article included the following major modules IU/FAS/PS/AM/DA/MDA/ATM.

A. Test Objectives - The primary test objectives were to verify the structural integrity of the assembly when exposed to the acoustic environments, verify the dynamic design and test criteria for components and subassemblies and to qualify flight hardware components. The primary objectives of the VDT were verification of structural integrity and dynamic response characteristics, and the dynamic structural qualification of flight hardware components. The objective of the MST was to obtain modal data to be used in evaluating analytical results previously obtained using a mathematical structural model.

B. Test Results - The test objectives of the Skylab Payload Assembly test program, pertaining to MDAC-E supplied test hardware, were achieved. The structure withstood the maximum expected mission liftoff and boost acoustic and longitudinal axis VDT environments without failure or degradation. Data were obtained to verify or revise existing dynamic design criteria and to define new design criteria for specific components. Test criteria verification and revisions are presented in MDC Report E0545, dated 15 June 1973. Complete testing results for all components are documented in MSFC Report

Number S&E-ASTN-ADD (72-29), dated 12 July 1972; (72-62), dated 1 August 1972; (72-89) dated 8 November 1972.

5.3.2 Component/Subassembly Testing

In a small number of cases the specified component PIA test was waived. The general requirements for waiver were MDAC-E Quality Control and engineering witness of the suppliers bench test, and handcarry delivery. Other considerations were past history, retest capability after installation, and possible schedule ramifications. Of those functional components flown on Skylab I Airlock Module, 1180 were designated for preinstallation test and 46 PIA waivers were processed. The controlling document for PIA testing was SEDR D3-2.

Approximately 70 subassembly type tests were performed for the Airlock Module. These tests ranged from plumbing leakage and flow tests to detailed functional tests of complicated electronic systems with some of the system comprised of loose components and/or simulators. As an example, the Electronics Module 3 and 4 test was essentially a bench test of the complete instrumentation system prior to its installation on the spacecraft.

5.3.3 Spacecraft Systems Testing

Prior to the arrival of the Multiple Docking Adapter at MDAC-E from Martin Marietta Corp., the Airlock Module systems were tested both as individual systems and in combined systems operational modes. At the time this phase of testing was initiated the Airlock Module was not complete in that three subassemblies were not installed (coolant pump module, O_2/N_2 control module, suit/battery cooling module), some components such as sensors were missing and some hardware such as the ten-watt transmitters, battery chargers, flexible ducts and tape recorders were of nonflight configurations. However, enough equipment was installed to begin productive testing. Installing and/or replacing of the required hardware was conducted in parallel with the test activity. The decision to begin the test activity was made with NASA concurrence.

This activity established confidence in the Airlock Module systems to perform as systems and to provide interface interactions with other Skylab Modules.

5.3.4 Integrated Systems Testing

5.3.4.1 AM/MDA

Upon completion of the initial Airlock Module testing, the MDA was shipped from Martin Denver to MDAC-E by Super Guppy aircraft. The MDA was mated with the Airlock Module twice, the first mate being for the purpose of mechanical interface and clearance checks. During this mate the AM/MDA was mated to the Fixed Airlock Shroud. The ATM Deployment Assembly was then mated to the FAS and mechanical deployment performed. The stack was disassembled and the MDA was then permanently mated to the Airlock Module. See Figure 5-14.

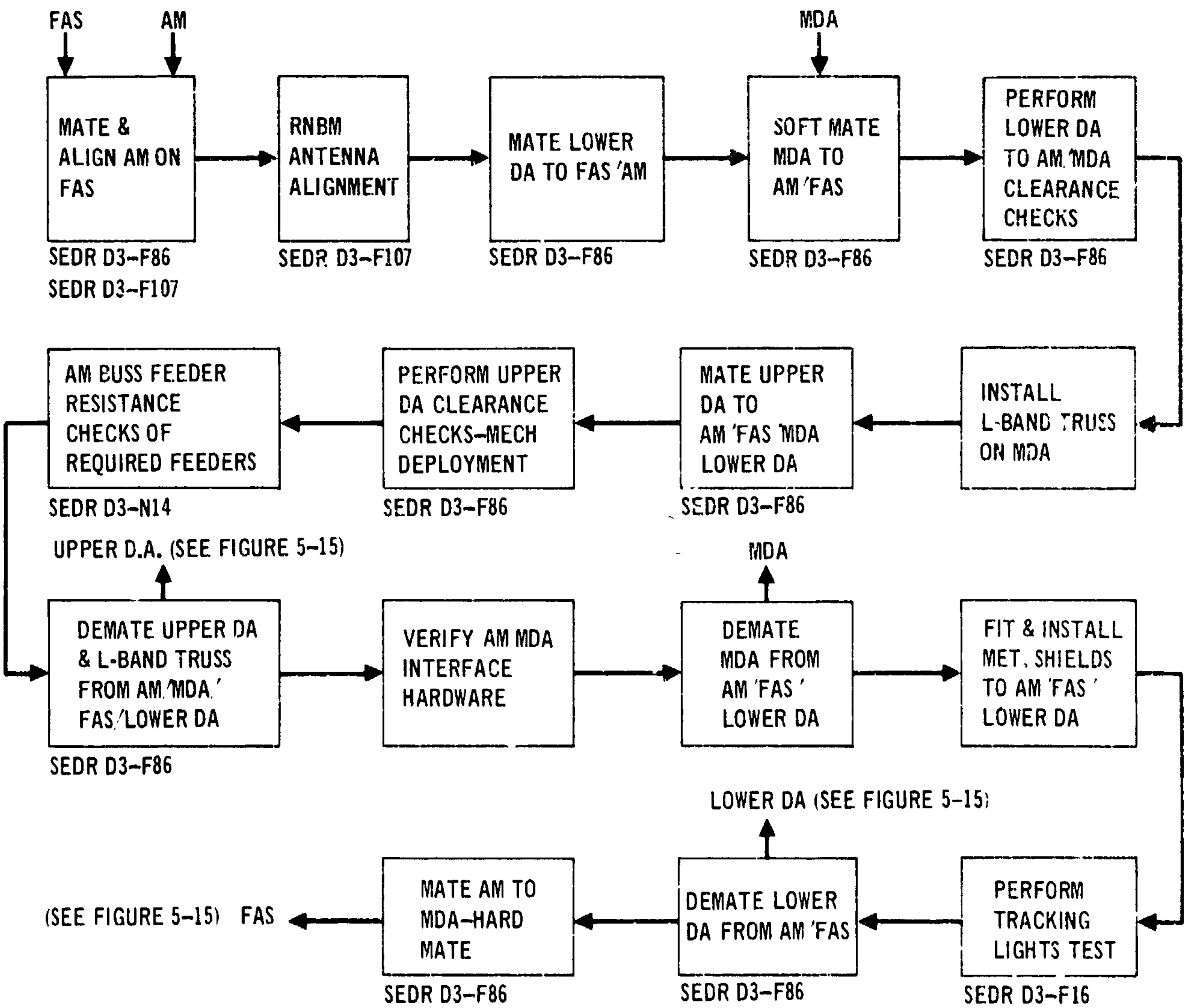


FIGURE 5-14 AM/MDA/FAS/DA MATING ACTIVITY

The MDA was delivered to MDAC-E with several pieces of hardware either not installed and/or tested. The principal components were the five Earth Resources Experiment Package (EREP) and the ATM control and display console. This hardware was installed and tested at MDAC-E prior to delivery of the AM/MDA to the launch site.

Testing during this period included the systems assurance test of each system of the mated AM/MDA, Crew Compartment Fit and Function (C^2F^2), a Simulated Flight test wherein systems were operated in the expected flight sequences, the Manned Altitude Chamber Test, completion of EREP and ATM C&D panel installation and test, and additional C^2F^2 and Simulated Flight tests to validate the late hardware. During this period the Astronauts participated principally in the C^2F^2, Simulated Flight test and Altitude Chamber tests. The crewmen for the Altitude Chamber test consisted of the prime crew for Skylab 2. The mated AM/MDA, the FAS and the DA were then prepared for individual delivery to John F. Kennedy Space Center by means of Super Guppy aircraft.

5.3.4.2 FAS and DA

Testing of the FAS and DA at the MDAC-E facility was primarily performed as parallel activity to the AM and MDA activity, as shown in Figure 5-15. The exception was the mate activity described in paragraph 5.3.4.1, during which the FAS-DA-AM and MDA were soft mated for interface and clearance checks. Activity prior to this time consisted principally of mechanical alignment of the DA, wiring checks and installation of equipment. During the mate activity, assembly alignment checks were performed for AM to FAS attachment, discone antenna mount and experiment S193 mount. Bus feeder wire resistance measurements were also performed.

Subsequent to both the demate of the FAS-AM-MDA-DA and the checkout of the FAS subsystem, the FAS and DA were again mated. During this FAS/DA mate the activity consisted of alignment of the discone antenna, mechanical deployment of the DA, and alignment of the DA in both the launch and deployed position. This was followed by DA functional tests including electrical deployment using individual and combined motor operations, and fit checks of installed equipments such as the experiment S-193. The DA was then demated, after which the FAS weight and center of gravity were determined and the unit prepared for delivery. Post demate activity on the DA consisted of weight and center of gravity determination followed by preparation for delivery.

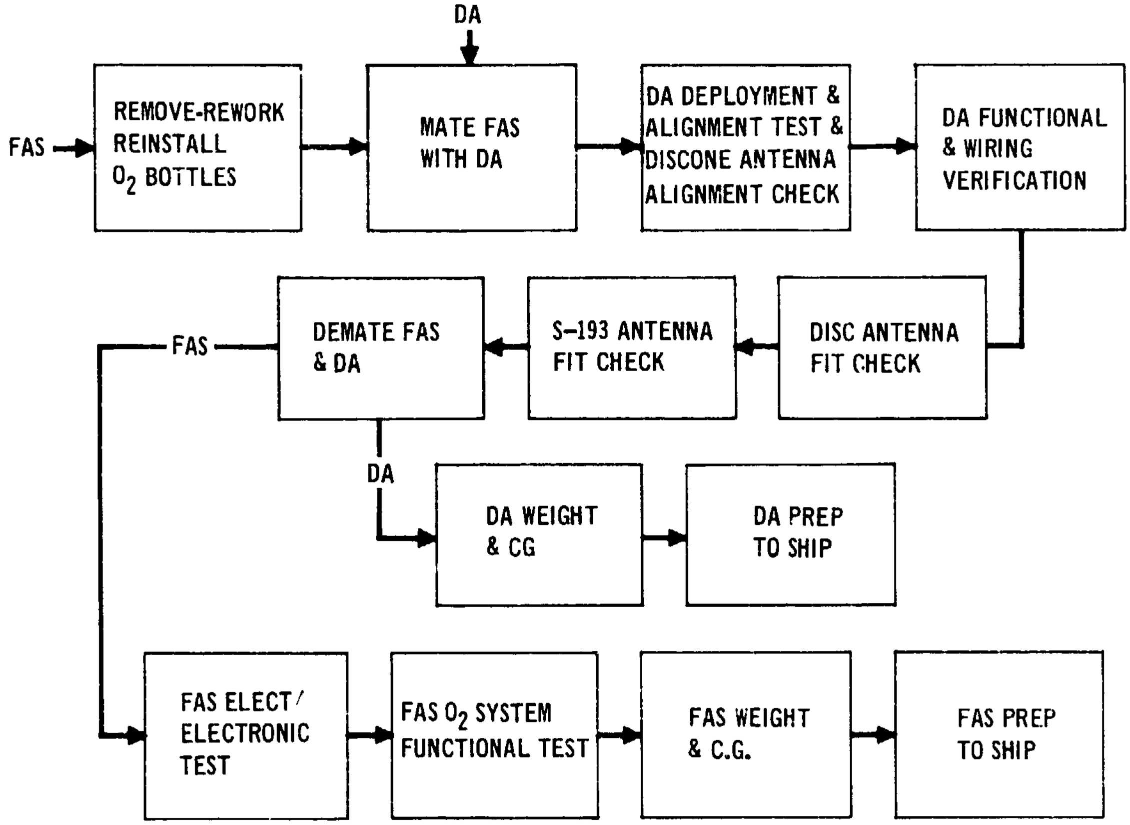


FIGURE 5-15 FAS AND DA TEST FLOW FOLLOWING SOFT-MATE ACTIVITY

5.3.4.3 Test Schedule at Contractor's Plant

Without doubt the most significant factor affecting the changes in the U-1 flight hardware acceptance test schedule at the contractor's plant was the continually changing delivery, installation and test schedule for the EREP hardware. Acceptance testing of the Airlock Module (Tunnel/STS) was originally scheduled to begin on 18 October 1971 with MDA delivery scheduled for 1 December 1971 as shown in the scheduled U-1 test flow chart given in Figure 5-16. At that time the MDA was to be delivered with the EREP installed and tested. Acceptance of the Airlock Module(Tunnel/STS) into the test activity actually occurred on 15 October 1971.

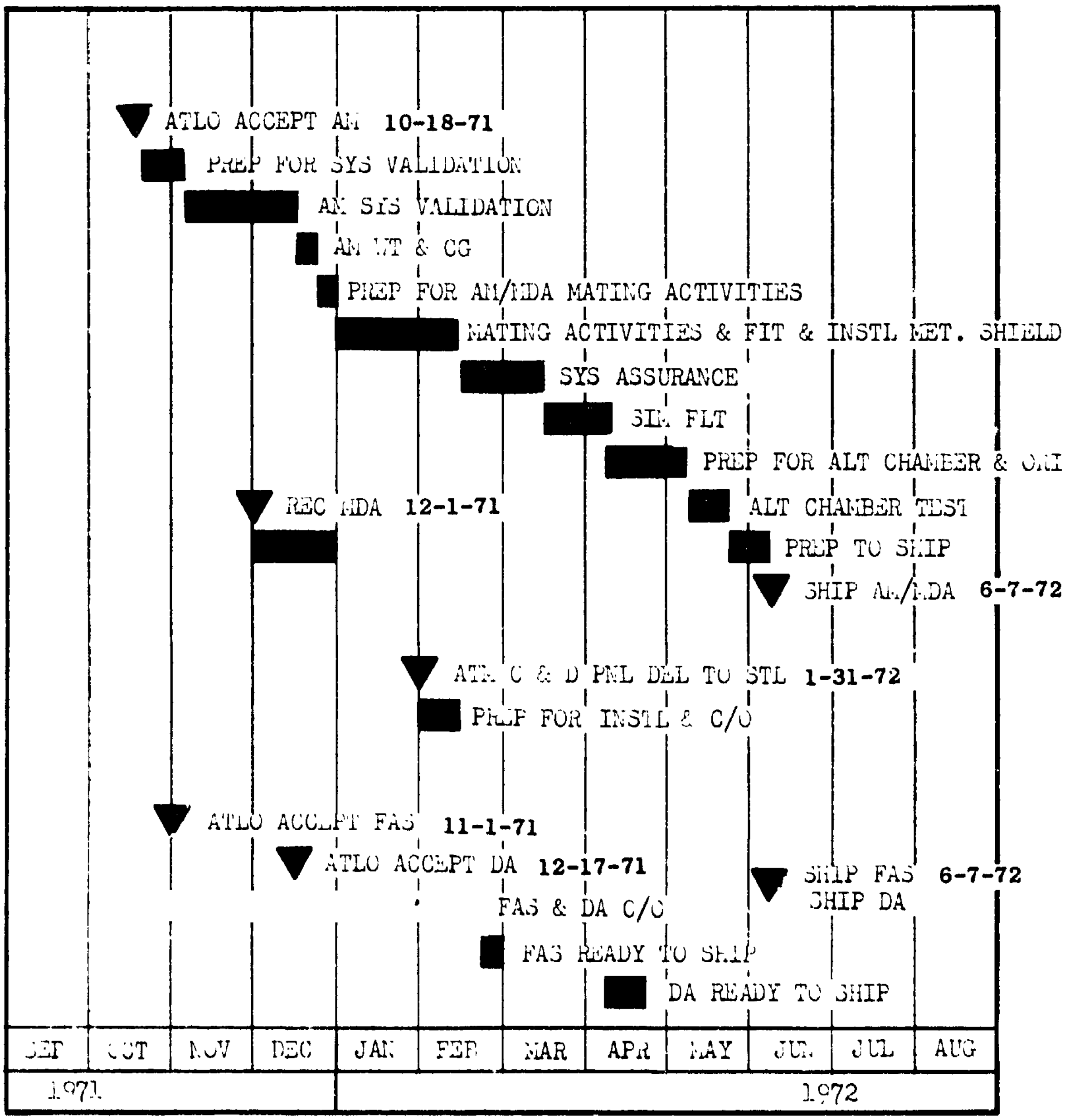


FIGURE 5-16 U-1 MDAC-E TEST FLOW - PLANNED

The MDA was delivered to MDAC-E St. Louis on 18 December 1971 (18 days behind schedule) and at that time contained no EREP experiments and only the cooling equipment and structural framework of the ATM C&D Panel. Delivery of the EREP experiments and the ATM C&D Panel continued to change throughout the activity at the contractor's plant. Delivery of the EREP experiments for installation and test was accomplished approximately 20 July 1972, or nearly eight months late. The total acceptance test schedule which at the start of testing was to culminate with delivery to the launch site on 5 July 1972, was actually completed 9 October 1972 as shown in the actual U-1 test flow chart given in Figure 5-17, or approximately three months later than had been planned at the inception of the test activity. The late delivery of experiments resulted in their not being exercised in two major tests, the Simulated Flight Test and the Altitude Chamber Test. After the Altitude Chamber Test, which was to have been the final test prior to delivery to the launch site, the AM/MDA was removed from the chamber, recabled, and the experiments were installed and validated in a second Simulated Flight Test (SEDR-D3-E74 Vol II). This additional post Altitude Chamber test activity accounts for approximately one-half of the three months schedule change. The remaining one and one-half months of schedule impact were caused by numerous minor problems, the most significant of which were thermal capacitor redesign, O_2N_2 module redesign, flexible metallic hose replacement, and the approximately 490 FJS's issued affecting the Airlock Module during this period.

5.3.5 Launch Site Testing

5.3.5.1 Test Activity

Although not a part of the Airlock contract, the following brief synopsis of launch site testing is supplied for continuity (see Figure 5-18 for the planned Airlock flow).

A. Upon delivery to John F. Kennedy Space Center, and after completion of receiving inspection, the FAS was installed in the Manned Spacecraft Operations Building West Integrated Test Stand (WITS). The AM/MDA was partially inspected and then mated to the FAS.

B. The DA and Payload Shroud were placed in storage in the MSOB and VAB, respectively. In order to minimize serial schedule time, receiving inspection of all major articles was performed on a noninterference basis. The Payload Shroud remained in the VAB until space was available

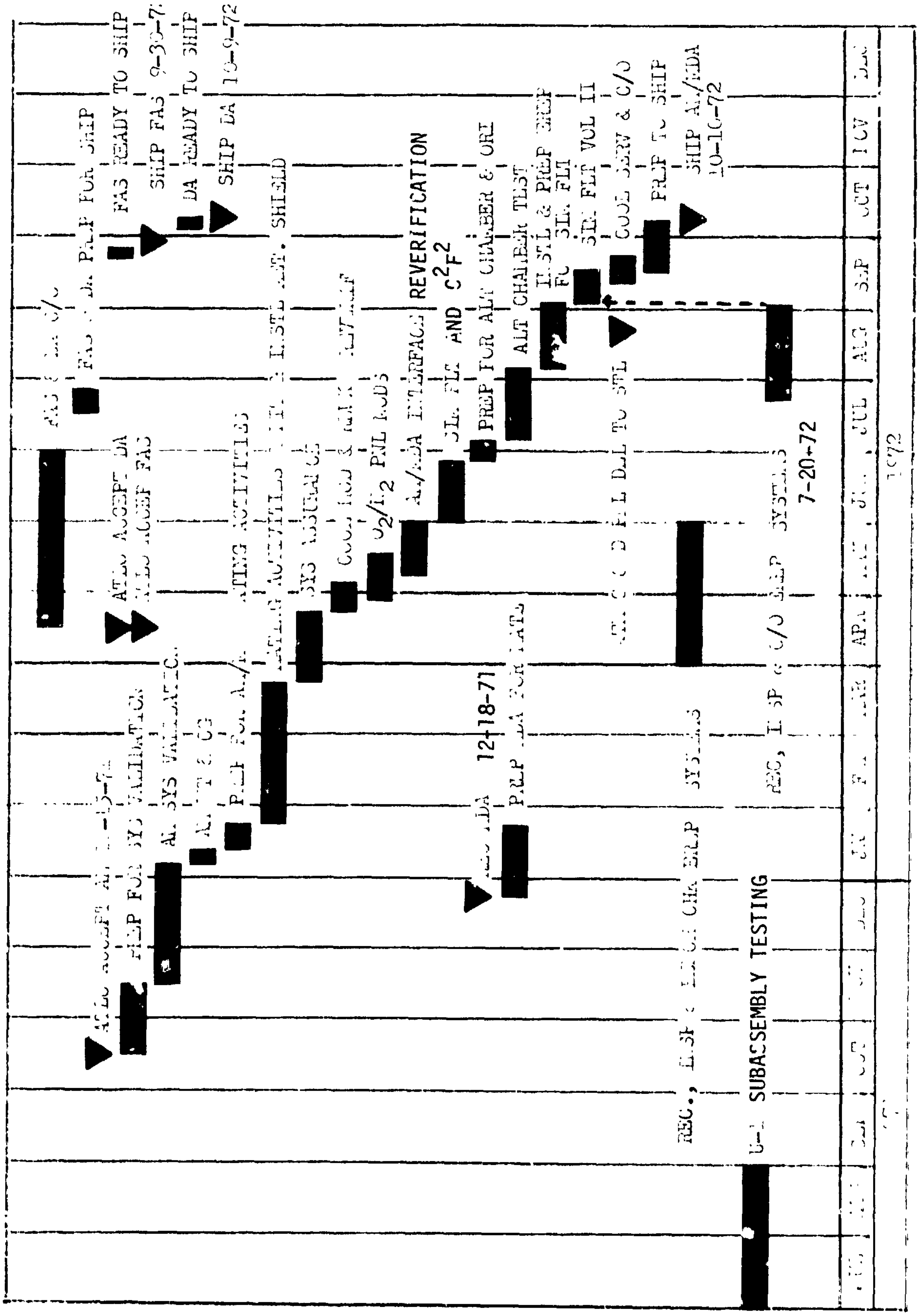


FIGURE 5-17 U-1 MDAC-E TEST FLOW – ACTUAL

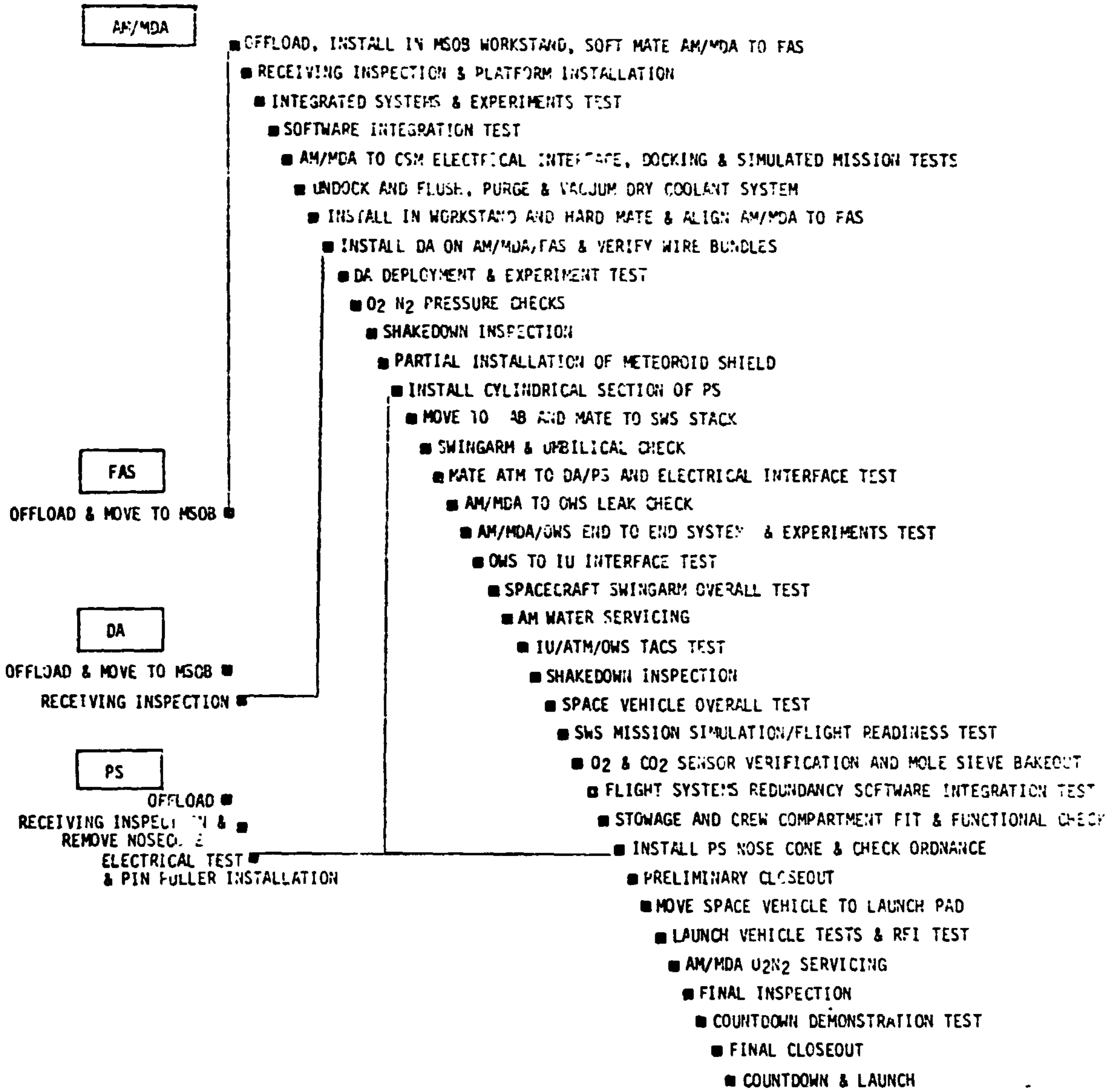


FIGURE 5-18 U-1 LAUNCH SITE TEST FLOW – PLANNED

in the MSOB at which time it was moved to the MSOB, the nose cone demated from the cylinder section and both sections again placed in storage. Both the DA and Payload Shroud remained in storage until just prior to their use. At the appropriate time, both were removed from storage inspected and prepared for use.

C. Following mate of the FAS and AM/MDA in the workstand, a detailed AM/MDA/FAS Integrated Systems and Experiment test was performed. Following this test and the performance of a Software Integration Test the AM/MDA was demated from the FAS and both were removed from the workstand. The AM/MDA was placed on the horizontal handling fixture. The Skylab 2 CSM was installed in launch attitude in the WITS stand and the AM/MDA supported in the inverted position above it. The AM/MDA was then lowered and mated with the Command Module. In this configuration, the AM/MDA/CSM Electrical Interface and Simulated Mission test was performed. Upon completion of this test the handling process was reversed ending up with the AM/MDA/FAS installed in the WITS in a hard mated condition.

D. The DA was removed from storage, inspected, and hard mated to the FAS in preparation for the DA deployment test. In parallel with the inverted docking test with the CSM and the DA deployment test, the Payload Shroud was removed from storage, inspected, an electrical systems test performed and the pin pullers were installed in preparation for mate of the cylinder to the FAS/AM/MDA/DA. Following the DA deployment test, the oxygen and nitrogen supply systems were tested at reduced pressure. The Payload Shroud cylinder was then mated to the FAS/AM/MDA/DA and the entire assembly was placed on a converted CSM transporter for the move to the VAB.

E. Immediately following transfer of the assembled FAS/AM/MDA/DA/PS cylinder to the Vehicle Assembly Building (VAB), the assembly was mechanically mated to the Instrumentation Unit (IU) interface of the LV/OWS/IU assembly. This was immediately followed by installation of the Apollo Telescope Mount into/onto the PS/DA. The single point ground was continuously monitored during the cabling operations and facility configuration activity in preparation for the next series of tests. The AM/MDA/OWS interface leakage test was performed in parallel with ATM Systems verification, both of which extended into initial portions of

the AM/MDA/OWS end to end systems and experiment test. The activity was followed by servicing of both the OWS and AM water systems which was performed in parallel with Launch Vehicle Lox and LH_2 leakage test and IU/ATM/OWS Thruster Attitude Control System (TACS) test. Approximately one week was then expended in shakedown inspection and cleanup in preparation for the Flight Readiness Test. Following the Saturn Workshop Mission Simulation/Flight Readiness test, verification of the Oxygen and Carbon Dioxide Sensors and Molecular Sieve bakeout was performed in parallel with the Flight Systems Redundancy Test and stowage of the vehicle for flight in preparation for the Crew Compartment Fit and Function (C^2F^2) evaluation. Following the C^2F^2 activity, final storage of all modules was accomplished in parallel with installation of the Payload Shroud nose cone. The nose cone was removed from storage, installed on its transporter, and Ordnance installed prior to being moved to the VAB for installation as the final portion of the Skylab I stack. Following nose cone transfer to VAB and its mate activity, Payload Shroud and launch vehicle ordnance was installed in preparation for the move to Launch Complex 39A.

F. Due to the unmanned status of the spacecraft at launch, the principal Airlock activity on the launch pad consisted of systems monitoring, oxygen and nitrogen systems servicing for flight and support of Countdown Demonstration Test and the Launch Countdown.

5 3.5.2 Test Schedule at Launch Site

At the time of delivery of the Airlock Module to the launch site, the launch date had been established as 30 April 1973. The actual launch occurred on 14 May 1973, two weeks later than had been planned, as shown in the U-1 test flow given in Figure 5-19. The change was caused by several major problem areas.

- EREP operational and installation problems.
- EREP plumbing incompatibility with working fluid.
- Electronic timer problems.
- Replacement of AM-EPS lights.

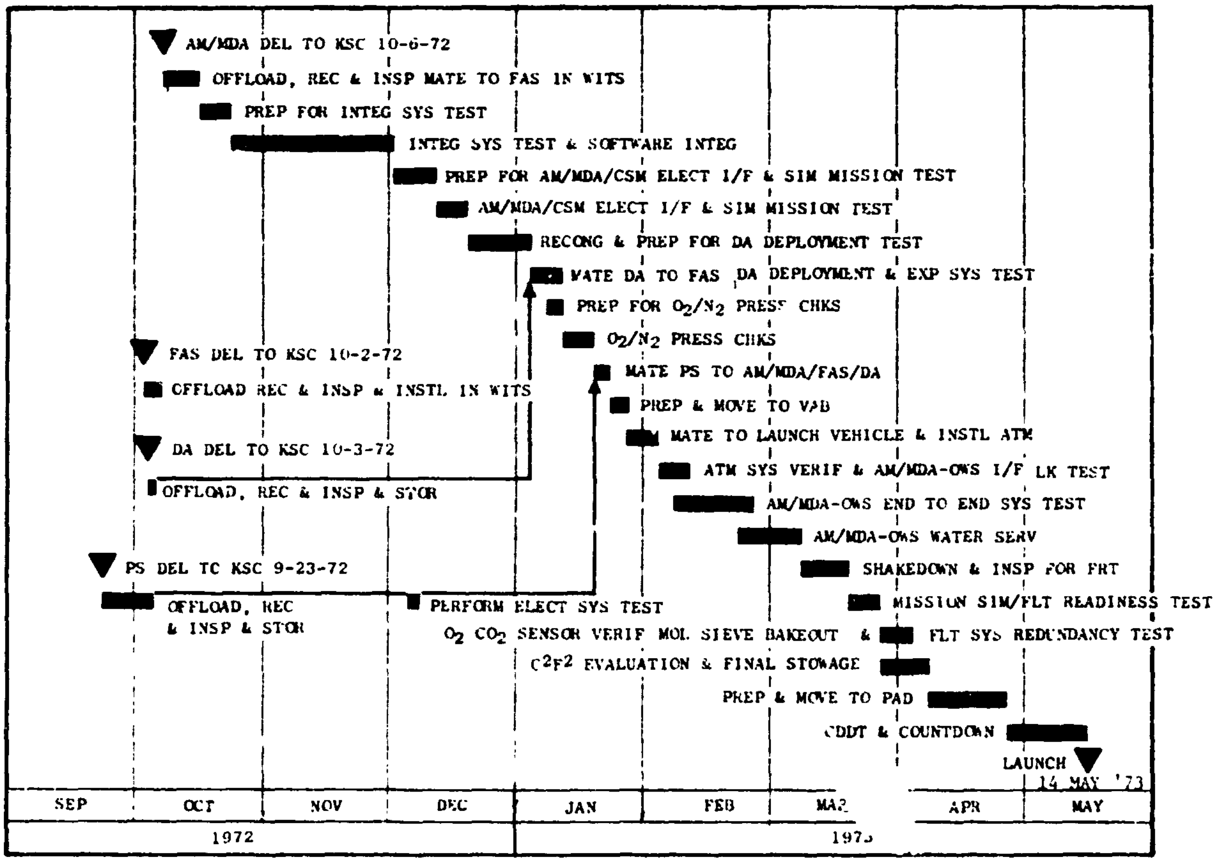


FIGURE 5-19 U-1 LAUNCH SITE TEST FLOW - ACTUAL

- Rework of O_2/N_2 control module.
- AM SUS pump problem.
- Replacement of IEU.
- AM circuit breaker problem.
- Replacement of relay panels.
- Over-optimistic scheduling of first-time operations.
- Single point ground violations.
- Inspection and sealing of AM heaters.
- Condensate transfer system plumbing mod.
- Water reservoir bladder and static grounding problem.
- Modification of SIA switches.
- Modification of Rapid Delta P sensor wire bundles.
- CRDU modification.
- Time correlation buffer mod.
- Additional transducer in secondary coolant system.
- 47 total spacecraft modification kits incorporated.

5.4 U2 VERIFICATION TESTING

U2 testing differed from U1 testing because of the different roles of the two vehicles. Because of the planned utilization of U2 in a mission support role for U1, various tests which were performed on U1 were not necessary for U2. In addition, certain tests performed on U1 were of a developmental nature and not required to be duplicated on U2. Differences in testing also resulted from hardware availability and different test flow sequencing between the two vehicles. Figure 5-20 presents the test flow sequence performed on U-2.

5.4.1 Tests Performed on U1 but Not on U2

- Altitude Chamber Test (D3-E73)
- Crew Compartment Fit and Function (C^2F^2) Verification (D3-F106)
- Development tests including coolant stabilization, M509 recharge, and toxicological tests
- ATM C&D Panel Verification (no flight hardware on U2)
- EMC test

5.4.2 Tests Performed on U2 Differently from U1

- Systems Validation and Systems Assurance test procedures which were performed separately on U1 were combined into a single test on U2.

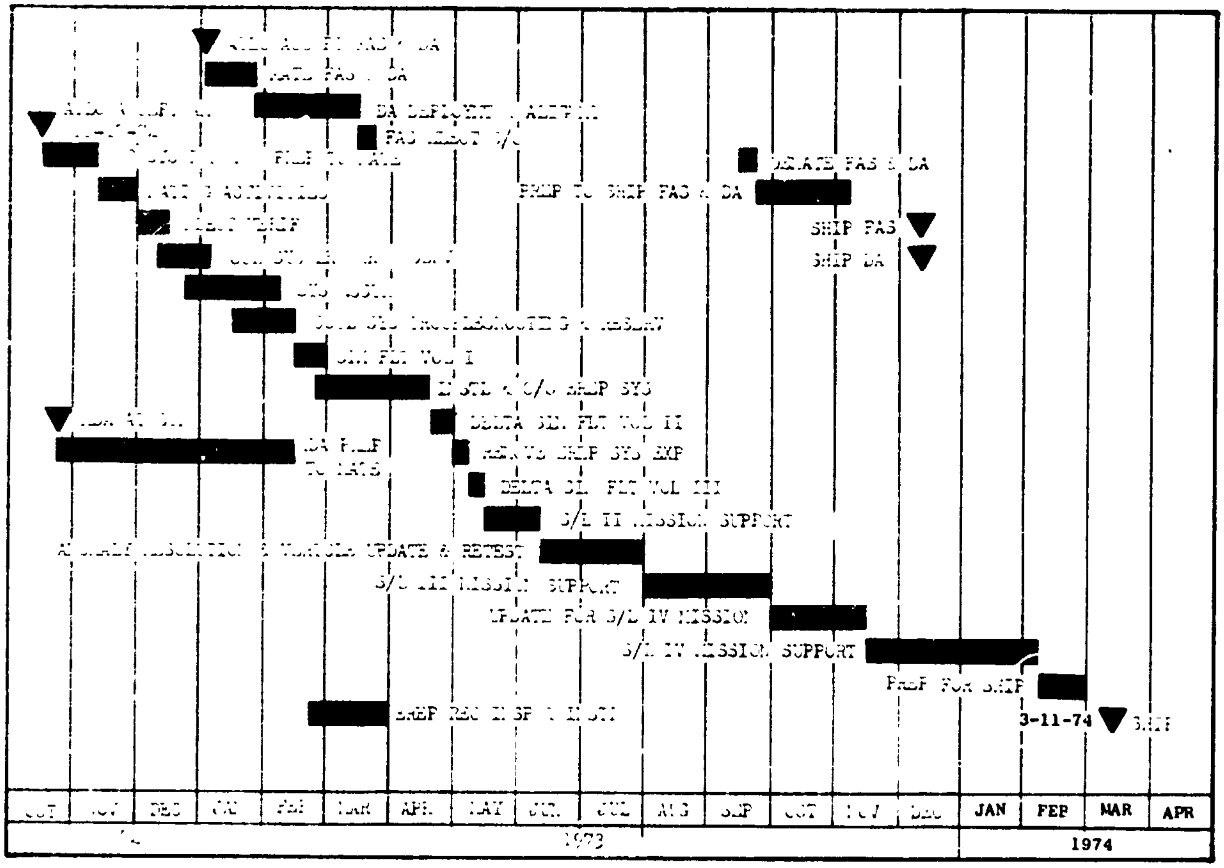


FIGURE 5-20 U-2 MDAC-E TEST FLOW - ACTUAL

- Simulated flight testing on U1 was performed before and after the Altitude Chamber Test. On U2, three Δ Sim Flight tests were performed - one prior to EREP installation, one after EREP installation, and one after EREP removal in preparation for mission support test activity.
- Reduced TV system testing on U2 because of nonavailability of flight hardware.

5.4.3 Tests Performed on U2 but Not on U1

- U1 Mission Simulation (D3-E77)
- U1 Mission Support Testing including development of hardware installation/change procedures and timelines, e.g., Coolant System In-Flight Reservicing, Heat Rejection, and Power Conservation Techniques.

5.5 MISSION SUPPORT TESTING

Ground test support of the Skylab Mission was established through the Mission Support Planning as defined in the Airlock Mission Operations Support Plan, dated 12 February 1973, and the Airlock Mission Support Hardware Plan, MDC E0571, dated 17 May 1972.

The purpose of the ground simulation test systems was to permit definition of system behavior under conditions peculiar to the flight or following a single or multiple failure occurrence. Ground testing permitted the projection of the abnormal or failure situation to other conditions under which the system was required to operate, and allowed definition of recommended procedures to be followed. In general, the test systems were required to be of a configuration to provide the following capabilities:

- Close approximation of the flight system
- Simulate flight component failures
- Impose transient boundary conditions such that the dynamic response could be determined
- Realistic interaction between systems
- Relatively rapid turnaround from problem definition to initial output of results.

To accomplish the above mission support testing objectives, three independent test systems and/or areas were utilized. They were:

- AM/MDA U2 Flight Vehicle.
- AM Environmental Control System/Thermal Control System (ECS/TCS) Skylab Test Unit (STU)
- MSF Skylab Test Unit/Spacecraft Tracking and Data Network (STU/STDN).

The coordination and monitoring functions related to the implementation of testing activities for the three test areas were provided for by the MDAC-E Airlock Project Engineering in conjunction with support from the MCAIR test lab personnel.

In addition, the Skylab Cluster Power System Breadboard, located at MSFC and identified as MSCB, was utilized by MDAC-E in conjunction with MSFC for mission support testing. Details of this mission support test activity are given in the Electrical Power System, Section 2.7.4.8.

Detailed definitions and a summary of the Skylab mission support testing activities performed at the three test areas are given in Section 7 of this report.

5.6 CONCLUSIONS

The test program philosophy of maximum use of existing qualified space hardware with extensive use of engineering analysis and previous test results to identify the minimum supplemental test program required to complete system verification was proven as a valid, economical approach to a successful mission.

Conformance to design requirements was adequately verified through the progressive building block approach to testing. As stated earlier, this approach not only provided for the solving of any problems, including successful retesting to demonstrate adequate performance prior to proceeding to the next testing phases, but, where hardware availability or unique problems arose, this test approach provided a means to utilize suitable workaround plans which were executed to assure complete and satisfactory testing on each system/subsystem component. As an example, the workaround plan philosophy was successfully utilized in the Integrated AM/MDA testing of U1 vehicle involving the problems of both the AM and MDA, such

as, thermal capacitor redesign and EREP and C&D panel hardware late availability.

As proven with this test program, some system problems are only detectable with all-up systems testing; therefore, it is desirable to initiate all-up system tests at the earliest possible time. Testing should include all system "ON" operational modes as well as all system nonoperational (dormant) modes to fully evaluate system hardware endurance and total system compatibility. For example, the AM SUS loop system/fluid incompatibility problem wasn't detected until all-up systems testirg was initiated.

In summary, the AM test porgram was considered highly successful in that both of the main program objectives were attained, i.e., delivery to the launch site of a satisfactorily operational spacecraft and launch of a problem free orbital vehicle.

SECTION 6 ENGINEERING PROJECT MANAGEMENT

The activities of Engineering Project Management included the following:

- Preparation and maintenance of plans and schedules.
- Support to engineering reviews such as Intercenter Panel Meetings.
- Support to project reviews such as the Critical Design Review.
- Preparation and release of engineering reports.
- Preparation and maintenance of Interface Control Documents.
- Configuration management functions.

The maintenance of schedules for planned work as well as authorized work allowed for accurate manpower planning. As a result system testing and hardware delivery occurred as planned with a relatively low expenditure of overtime.

Subsystem design reviews and intercenter panel meetings were the normal means for coordinating the Airlock design with NASA. However, a large increase in changes necessitated the formation of the Change Integration Working Group at MSFC that resolved inter-module problems and expeditiously made fundamental design decisions. MDAC-E also supported the Systems/Operations Compatibility Assessment Review that verified the integrated systems design and systems compatibility with operational procedures.

Appropriate support was given to the project reviews. There were no significant changes generated at these reviews due, in part, to the intensive daily engineering coordination that occurred prior to those reviews.

The significant engineering reports related to the AM performance/configuration CEI specification and to test requirements for verifying the design and manufacturing of the Airlock. These documents were of sufficient detail and were maintained current to permit complete performance/configuration validation by the time of FRR.

The Airlock, due to its relationship to the Skylab system, had an important part of interface coordination. MDAC-E was custodian of 28 Interface Control Documents (ICD's) and participated in the maintenance of another 58 ICD's. A total of 2083 changes to these ICD's were developed and coordinated/evaluated. There were no discrepancies caused by incorrect or incomplete interface requirements during cluster stacking/checkout, at KSC or during mission operations.

Configuration management had three elements; (a) Identification, (b) Change Control and (c) Verification. Configuration requirements were identified in the CEI Specification, Power Allocation Document, Stowage List and ICD's. These documents were continually updated to include approved changes. In response to NASA direction, Engineering Change Proposals were submitted in accordance with MSFC configuration management requirements. Prior to AM delivery, ECP turn-around time for submittals was 35 days; during the KSC activity expedited ECP's were submitted within one day of the defined requirement. Very close coordination with MDAC resident personnel at MSFC and KSC facilitated a short approval cycle and rapid initiation of the necessary work. Closing-the-loop was accomplished with the Configuration Status Accounting report that gave MSFC visibility on the approved and current configuration.

Essentially the Engineering Project Management activities were a technical communication link between MDAC-E and MSFC that proved to be very effective.

6.1 PLANNING AND SCHEDULING

The purpose of planning and scheduling was to provide MDAC-E Engineering Management with the data necessary to control the scope and timing of work to meet schedule and cost commitments in the design, fabrication, and testing of the Airlock spacecraft. This activity was implemented by coordinating contractual commitments with work definitions, authorizations and goals, thus deriving basic work plans which described specific tasks, milestone events, schedule, manpower, facility, and hardware requirements. These work plans, which were continually updated to reflect changing hardware and budgetary requirements, formed the data base for all Airlock Program planning, scheduling, and management.

6.1.1 Engineering Schedules

The schedules that were used to support Engineering Program Management were:

- Engineering Master Schedule
- Department/Group Schedules
- Request for Estimate (RE) Schedules.

These schedules were built using as their resource NASA and MDAC-E Program milestones, manpower availability, Engineering work flow, etc.

A. Engineering Master Schedule - The Engineering Master Schedule was the basic schedule which incorporated the overall Program Management plan and the NASA Contractual Requirements into a totally coordinated effort. See Figure 6-1 for sample.

B. Department/Group Schedules - Using the Engineering Master Schedule as a basis, detailed work plans and schedules were made for Airlock functional department and group disciplines. The drawing release dates on these schedules were coordinated with manufacturing management and the staffing requirements were coordinated with functional department heads. These plans and schedules also were used in preparing department manpower forecasts, estimated overtime needs and budget coordination that allowed for appropriate transfer of personnel. A complete "Engineering Status" was maintained on a daily basis and published weekly as a management aid in monitoring all aspects of the engineering effort.

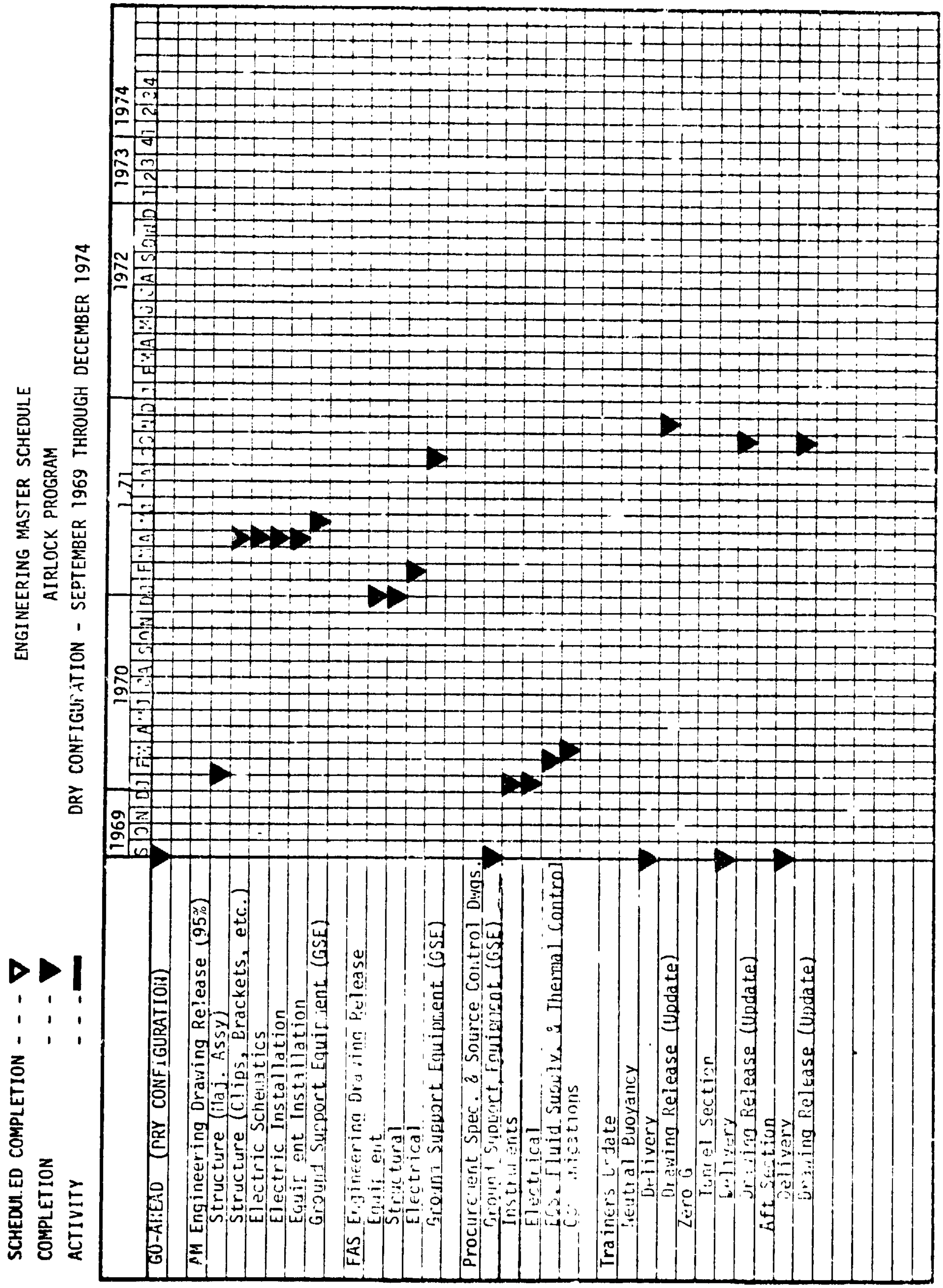


FIGURE 6-1 ENGINEERING MASTER SCHEDULE – SAMPLE

C. Request for Estimate (RE) Schedules - Engineering schedules with estimated manpower requirements were provided for each Request for Estimate received. An RE schedule was written for each Airlock Contract or Engineering Change Proposal (CCP/ECP) requiring more than 600 man-hours of effort. These schedules and estimates were used as the source for engineering schedules and CCP/ECP submittals.

6.1.2 Acceptance Test Master Schedule

Figure 6-2, the Acceptance Test Master Schedule scheduled two phases of test activity: early test activity performed during the Airlock manufacturing phase, and the later test activity, including assembly and installation tasks, of total Airlock/MDA checkout through delivery. The earlier portion of the schedule included all the subassembly tests and tests on the AM spacecraft major assemblies prior to completion of the manufacturing build-up phase, and was based on expected manufacturing completion dates of the various subassemblies and/or subsystems. This schedule was updated as required to reflect current hardware status, program changes, hardware delivery changes, and impact of test-related problems. Initially based on a five-day, two-shift work week, the final schedule provided for a seven-day, three-shift work week for all major test activity in order to avoid daily power-up/power-down delays and to insure "on schedule" delivery. Two detail schedules, the Two-Week Work Schedule and the Daily Work Schedule, supported the Acceptance Test Master Schedule. These schedules gave management the flexibility to adjust the day-to-day test/hardware flow.

6.1.2.1 Two-Week Work Schedule

Based on the Acceptance Test Master Schedule, the Two-Week Schedule alerted ATLO personnel to any sudden changes or problems. This schedule was updated once a week and was used to provide more detailed visibility of the short range test program.

6.1.2.2 Daily Work Schedule

A daily work schedule was prepared after a review of work accomplished during the preceding 24-hour period and projected the work planned for the ensuing 32 hours. This schedule, based on accomplishing the activities planned in the

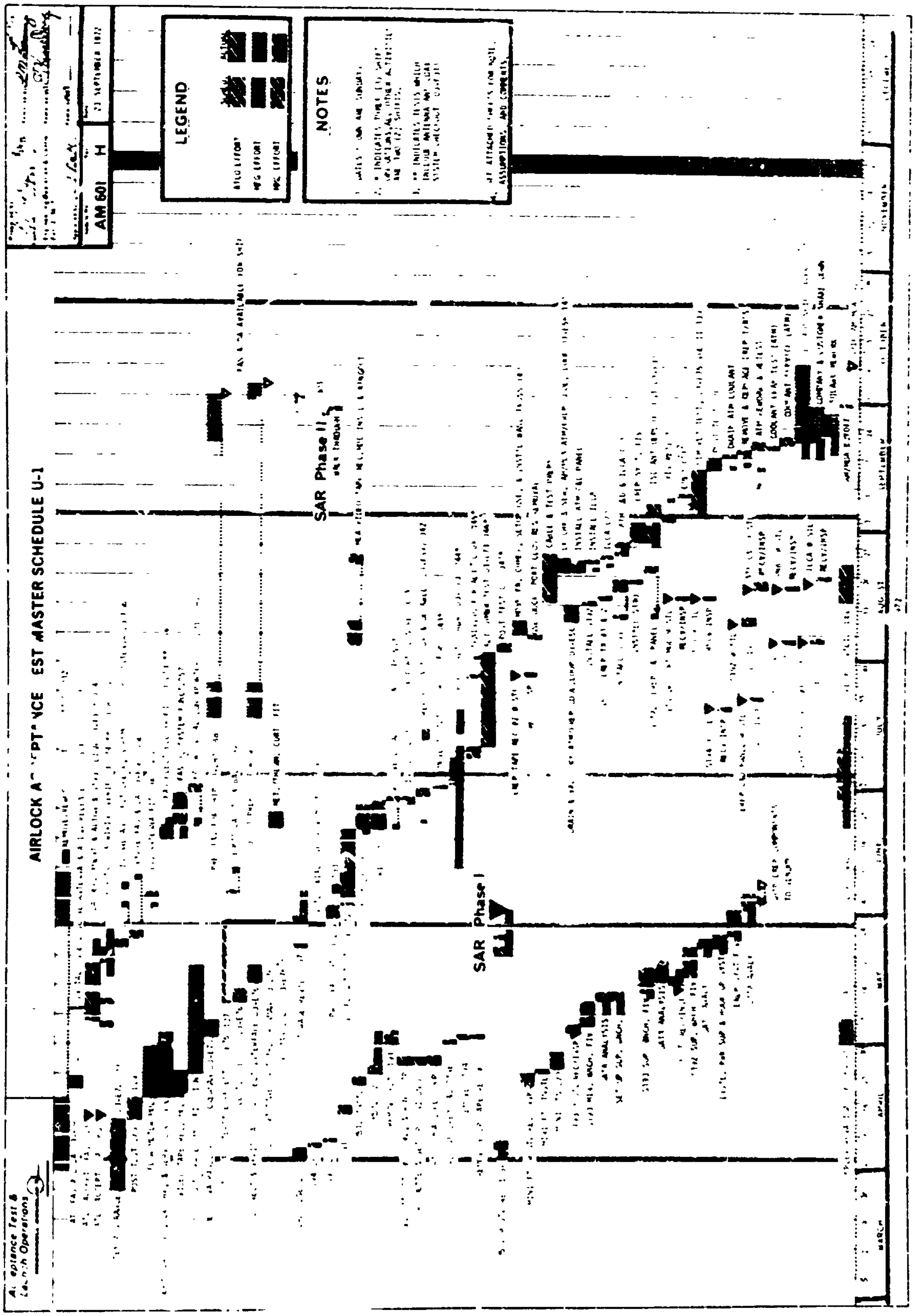


FIGURE 6-2 ACCEPTANCE TEST MASTER SCHEDULE – SAMPLE

Two-Week Schedule, provided the authorization for day-to-day deviation of the test program. This schedule was prepared at a daily meeting with representatives from Manufacturing, ATLO groups, Procurement, Production Control, Quality Control (MDAC-E and NASA/USAF), Design Engineering, NASA Resident Office and Martin Marietta Company.

During the test phase, fabrication/assembly was occasionally required as a result of late hardware deliveries, program changes, or test activity problems. This dual effort was coordinated by the test activity in accordance with the Daily Schedule and acceptable safety precautions.

All instructions for accomplishing new engineering and engineering changes on the spacecraft were documented on manufacturing planning sheets. These planning sheets were reviewed and approved by ATLO Operations after coordination with the groups involved. However, implementation of the instructions/work was not accomplished until authorized by the Daily Schedule.

6.1.3 Engineering Job Sheets (EJS)

The fundamental control document covering engineering effort was the EJS, which defined an engineering task and scheduled completion time. It outlined the detailed engineering effort and required coordination between disciplines, estimated engineering manhours allocated to the task, and specified schedule impact. Upon initiation the basic EJS, showing description and purpose, was distributed to all concerned engineering groups for their evaluation of work impact, time estimates, etc. After the supplemental information was collected, the EJS was then approved by the Engineering Manager. Upon his approval, the Engineering Work defined by the EJS was started. The EJS was then distributed to divisions, such as, Manufacturing, Procurement, Logistics, etc., for review and a Change Board was scheduled to evaluate total program impact. Authorization by the Change Board permitted all divisions to start work. After completion of all engineering effort, the EJS was reviewed by management and then authorized to be closed. EJS's were prepared to define work for hardware, test, and study activities. Each EJS was monitored to assure that the defined work was accomplished on schedule and within budget. EJS activity was reviewed

daily and a status given to management on a weekly basis. A total of 2146 EJS's were initiated for the Airlock Project. See Figure 6-3 for a flow plan of the EJS procedure.

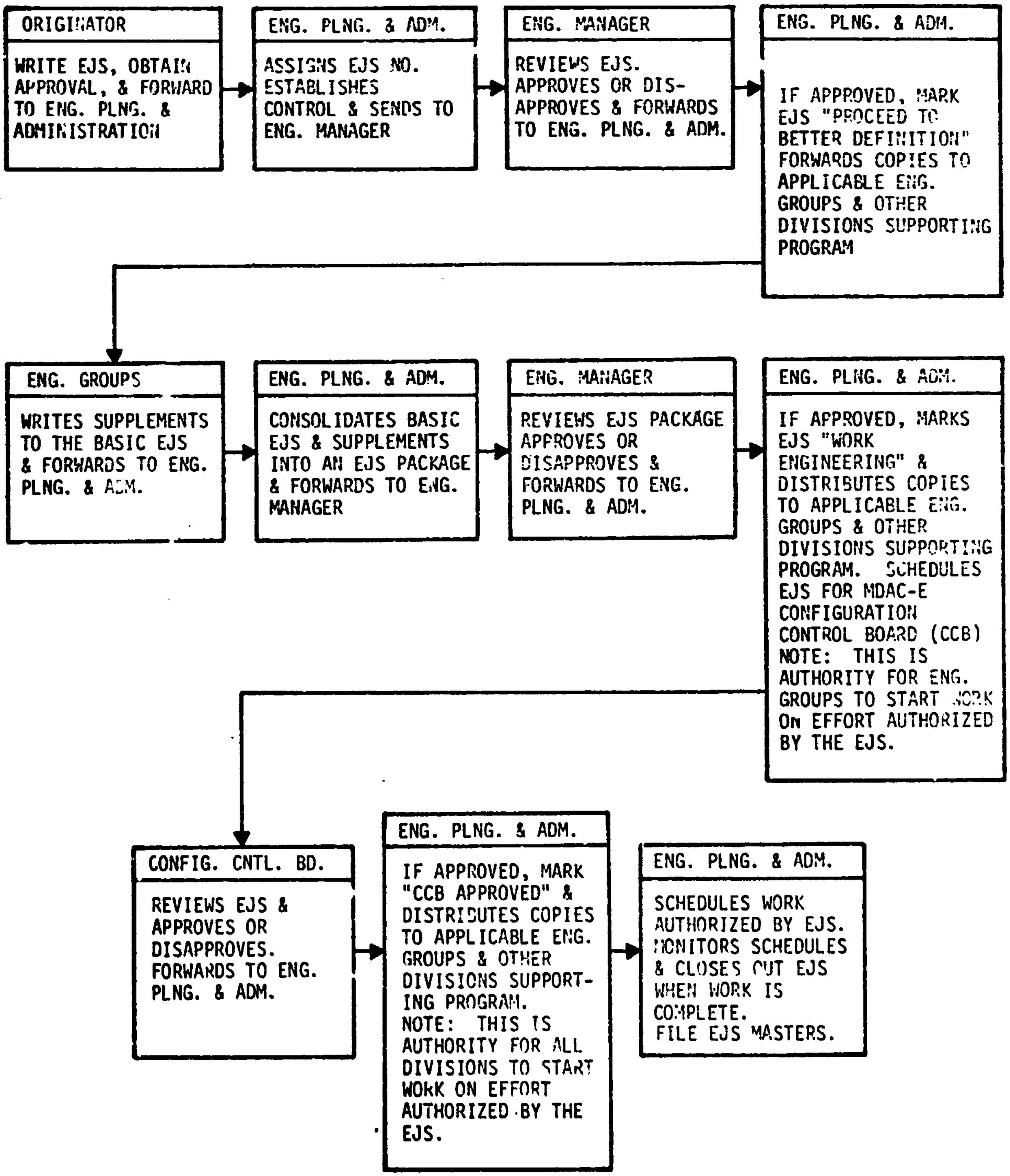


FIGURE 6-3 ENGINEERING JOB SHEET FLOW PLAN

6.2 ENGINEERING REVIEWS

A series of major Engineering Technical Reviews were held during the Airlock Program to assure the integrity of the Airlock. Included were:

- Subsystem Design Reviews
- Equipment Acceptability Reviews
- Change Integration Working Group Reviews
- Intercenter Panel Meetings
- Skylab Systems/Operations Compatibility Assessment Review (SOCAR)
- System Safety Review
- Hardware Integrity Review

The following discussion will briefly describe the subject reviews, the support given to the reviews and the review accomplishment.

6.2.1 System/Subsystem Design Reviews

System/Subsystem Reviews were technical reviews conducted on an approximate bimonthly basis between MDAC-E and MSFC Engineers. The purpose of these reviews was to assure a mutual and continuing NASA/Contractor understanding and agreement of the baseline system/subsystem designs. Particular emphasis was placed on the detailed engineering and supporting analysis, interface considerations and the suitability of tolerances and performance parameters.

There was a total of 1[illegible]8 subsystem reviews held as indicated in Figure 6-4.

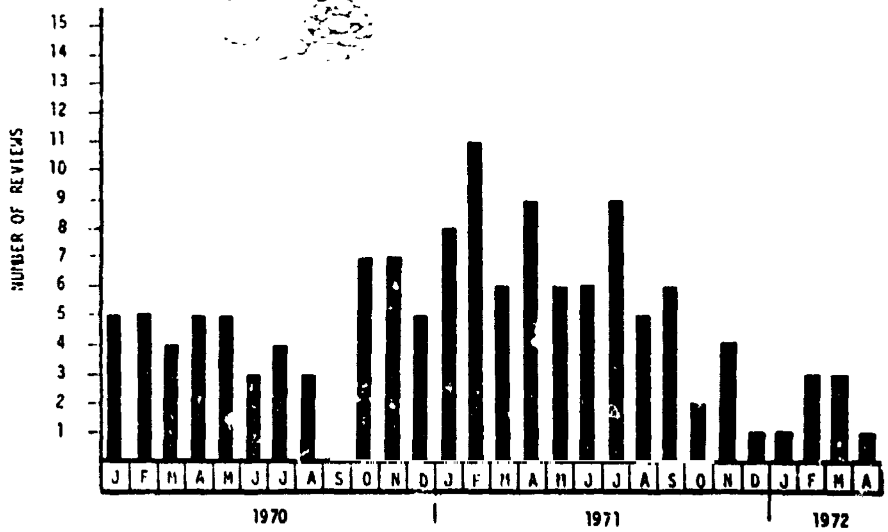


FIGURE 6-4 SYSTEM/SUBSYSTEM DESIGN REVIEWS

6.2.2 Equipment Acceptability Reviews

These reviews were started in April 1967 and were held on each item of equipment used on or furnished by the Airlock Project.

The reviews were conducted to assess the acceptability of the equipment for use on Airlock and evaluated all past history of the equipment on a component basis, including all previous testing, and compared it with Airlock environmental and mission requirements. As a result of these reviews, the equipment was either accepted as is or additional testing, analysis or documentation was requested. These additional requirements were in the form of action items transmitted formally by the NASA and were resolved to the NASA's satisfaction before final approval of the part was issued.

In support of these reviews, MDAC-E prepared forms on each item of equipment, summarizing qualification or development testing, reliability assessment, mission duty cycle, materials, demonstrated and expected life, and a number of other items pertinent to the history of the part. MDC Report G499, Volumes I through V, is a compilation of all Equipment Acceptability forms. Action items resulting from the reviews were closed and submitted for the NASA approval by formal transmittal of updated review sheets. To support these reviews MDAC-E maintained a Data Bank which contained documentation on the history of each piece of equipment being used and the results of all past environmental and development testing as well as similarity documentation.

A total of 2180 components were evaluated in detail during the review period.

6.2.3 Change Integration Working Group and Configuration Control Board

A program analysis conducted in July 1970, by both MDAC-E and MDAC-W, indicated that the program change traffic was growing at an alarming rate. As a result, NASA established a Change Integration Working Group (CIWG) and conducted Level I Change Boards weekly. Early in August 1970, NASA requested MDAC management to support these NASA configuration change meetings and to provide necessary data to expedite processing of Skylab changes. Changes considered were those emanating from the following sources:

- Engineering Change Requests (ECR) from MSFC.
- Engineering Design Change Requests (EDCR) from MSC.
- Change Requests (CR) from KSC.
- Engineering Change Proposals (ECP) from contractors.

By supporting the meetings with high level management personnel and by responding rapidly to the agenda items with Airlock impact data, MDAC-E contributed to timely resolution of pending changes, avoiding the higher program costs of implementing changes at a later date. The effectiveness of these meetings was proven by the quick resolution of changes that had been pending for several months.

The Change Integration Working Group (CIWG) was active at a time when the change traffic was heaviest. In August of 1971 the role of CIWG was expanded to include reviewing those outstanding Skylab ECP's considered to be delinquent. This change of role increased the demands on MDAC-E to provide additional information, to track status of ECP's and interface changes and to provide increased support for the CIWG Meetings.

6.2.4 Intercenter Panel Meetings

Project Management responsibility for the various elements of the Skylab Program was delegated to the appropriate NASA Centers. This delegation of project responsibility to more than one Center required the establishment of a formal process to define, coordinate, and control intercenter interfaces and to resolve interface related problems. A task team comprised of senior representatives from the Program Offices at MSFC, JSC, KSC, and OMSF defined an interface system to provide the coordination and control activity required. Panel co-chairmen and senior member appointments were made by the applicable centers. Subpanels were established as required by the panel co-chairmen and senior members. The panel co-chairmen were responsible to the Program Managers for implementation of panel decisions reached in panel meetings.

Statements defining the scope, objectives and responsibilities of the panels were tailored to the particular system assignment of each individual panel. However; in general, the objectives and responsibilities of each panel

were to assure the definition and control of interfaces associated with the performance requirements and operation of systems and experiments and to assure resolution of interface problems. Additional responsibilities of the panels were to define, resolve, and document recommended changes to those documents containing technical requirements which constrain interfaces and to review and assure overall systems performance compatibility.

The panel meetings were scheduled on a monthly basis and from these panel meetings many work group meetings were generated.

Each technical discipline in MDAC-E provided support to the intercenter panel meetings and working groups from inception through launch.

6.2.5 Skylab Systems/Operations Compatibility Assessment Review (SOCAR)

The SOCAR was conducted in two phases. The first phase extended from November 1971 until April 1972; the second phase was conducted during May and June 1972.

The primary objectives of SOCAR were to assess: (1) the Skylab systems design integration and performance characteristics based on updated engineering analyses, simulations, and actual hardware test experience, and (2) the operational readiness of Skylab through a detailed review of the mission documentation, plans, and techniques to be used by the operations team to conduct the mission.

MDAC-E supported and participated in reviews with the applicable NASA SOCAR teams for the following systems:

- Electrical System/C&W System
- Structural/Mechanical System
- Instrumentation/Communication System
- Thermal/Environmental Control System
- Special Emphasis Systems

- Stowage
- EVA
- GSE
- Attitude Pointing Control System
- Material
- Experiments

Task guidelines which were common to most SOCAR activities and to the MDAC-E effort are listed below.

A. Provided physical and functional summary descriptions of the applicable AM systems; listed and defined the location of its major components, identified critical items and single point failures, and assessed system reliability.

B. Summarized major changes since CDR.

C. Summarized system performance including waivers and deviations, special performance characteristics, and operating constraints determined from analysis and testing.

D. Identified system operational constraints and flexibilities related to flight crew and/or ground crew operations.

E. Reviewed applicable mission operations documents for accuracy and comprehensiveness.

F. Assisted team reviews for the applicable systems including preparation of presentation material and resolution of activities assigned by MSFC.

Considerable technical effort was expended by Airlock Engineering personnel in support of SOCAR. The expenditure of this time was well justified in that it provided the only opportunity for a formal end-to-end assessment of the system design, performance characteristics, and operational readiness of Skylab. These reviews did not identify the requirement for any Airlock design changes but did reveal numerous incompatibilities in mission oriented documentation and did significantly increase the vehicle operational confidence level.

Final SOCAR reports were submitted to the NASA in May 1972. All further MDAC-E effort on SOCAR was terminated in June 1972.

6.2.6 System Review by the NASA Aerospace Safety Advisory Panel

At the request of the NASA Administrator, the NASA Aerospace Safety Advisory Panel (founded by direction of Congress) undertook an extensive review of the Skylab Program and visited MDAC-E during the period of 8-9 November 1971 for a comprehensive review of the Airlock and Payload Shroud portion of the Skylab.

Effort was concentrated on contractor development and manufacture of Airlock and Payload Shroud modules and the associated NASA control activities. The primary concern in the review was the maturity of design and adequacy of test programs to validate suitability for the mission. Inherent in the review was a careful analysis of the methods of risk assessment and the means of implementing corrective actions where warranted.

Follow reviews were accomplished both at the responsible NASA center (MSFC) and by attendance at the AM/MDA Acceptance Review held at St. Louis 27-29 September 1972.

As a result of the review the panel expressed its satisfaction in all areas and evidenced concern only in that a combined ECS and EPS systems test to include the ATM, OWS, MDA and AM equipments was not planned by the NASA prior to actual flight.

6.2.7 Hardware Integrity Review

A Hardware Integrity Review Board was convened at MDAC-E, St. Louis, Missouri, on 22-24 March 1973. The object of the review was to examine in detail each item of the Airlock Module, FAS, DA and Payload Shroud equipment involved with all flight activation and critical mechanism operation sequences and to verify that it had been designed and tested to the environment to which it would be exposed. In order to accomplish this, MDAC-E provided extensive facilities and program data packages for the NASA Review Team's Evaluation, which preceded the formal Board Review.

The Flight Activation Sequence document was used as a baseline in the system review and was surveyed by all technical MDAC-E disciplines to list all equipment applicable to each and every flight sequence.

These components were then evaluated for their qualification requirements, tests conducted, manufacturing processes and procedures, failures or anomalies, materials differences between qualification and flight hardware, design differences between qualification and flight hardware, waivers or deviations, system application or procedural changes since qualification. This survey was then documented for each component and held for MDAC-E presentation to the Board. A total of twenty-seven action items resulted from the presentations. In addition, several supplemental tests were requested:

- Coax switch vibration and corona test
- Circuit breaker panel vibration test/overtest
- Discone antenna boom release module rigging cable vibration and functional test
- Launch mode accelerometer amplifier vibration testing
- EVA hatch window cover pressurization test.

All action items were completed during the course of the review to the Board's satisfaction. At the conclusion of the Board Review, MDAC-E was commended by the Chairman on a "job well done," at which time the NASA stated that they were "impressed" with the MDAC-E reaction to the review request and with "the volume and detail of work that MDAC-E accomplished in such a short time." All supplemental testing was successfully completed prior to FRR.

The depth and satisfactory results of the review gave added assurance to both the NASA and MDAC-E that all flight equipment had been adequately designed and tested and that it would satisfactorily perform during the Skylab Mission.

6.3 PROJECT REVIEWS

MDAC-E provided technical support for all Project Review teams. This consisted of assistance from at least one systems engineer, for each system, who was available for consultation with the review team on an "as required" basis for the duration of each review. MDAC-E also provided administrative support as required for the duration of each review and provided data books of the systems status, including the qualification status of equipment, configuration and reliability status. Data books of the Review Item Discrepancies (RID's) resulting from the review were prepared for the NASA Formal Board disposition.

6.3.1 Preliminary Design Review (PDR) - Held at MDAC-E on 29 November 1967

The purpose of the review was a formal review of the basic design requirements of the Airlock and all associated ground support equipment to determine the acceptability of the engineering approach. The acceptability of this approach was determined through the review of specifications, drawings, analyses, test data, mockups or breadboard models, and interface requirements.

The Review Board dispositioned a number of RID's as a result of this review most of which were in the software category. However, there were a number of hardware changes affecting design and configuration of equipment. An example of the hardware impact was the requirement for a redundant condensing heat exchanger. This addition caused relocation of the existing unit and necessitated additional ducting plus addition of a gas selector valve to isolate the dormant unit. It also required additional structural support and the addition of coolant and water lines.

The requirement for a centralized Crew Station to be located in the STS also resulted from the PDR. This change required the moving of the forward compartment Circuit Breaker Panel to the STS and caused the replacement of stringers with machined fittings to support the panel ("Wet Workshop" configuration).

6.3.2 Cluster System Design Review (CSDR) - Held at MSFC on 2-4 December 1969

MDAC-E provided support for the Cluster System Design Review held at MSFC on 2-4 December 1969. The objective of this review was to determine the extent to which the cluster system contractors complied with the requirements of the Cluster Requirements Specification RS 003M00003. MDAC-E was requested to provide support in evaluating and responding to 41 action items by preparing impact statements where required. This effort continued through to 1 February 1970. The impact of full compliance with the Cluster Requirements Specification (CRS), dated 8 August 1969 including Change Packages 1 through 22 was defined in ECP-114 submitted on 5 November 1970. Subsequently, MSFC directed that MDAC-E use the CRS as a general design guide only.

6.3.3 Critical Design Review (CDR) - Held at MDAC-E on 10-14 August and 1 September 1970

The CDR was a formal review of the detail design of the Airlock and all associated ground equipment. Particular emphasis was placed on the detail engineering and supporting analyses - such as stress, vibration, and launch acoustic analysis upon which the design was based - the detail interface considerations, and the applicability of detail tolerances and performance parameters. During this review all existing interface documents were reviewed and open interface requirements were assigned for early resolution.

The review resulted in Board disposition of 10 RID's that affected hardware design and four that required additional testing. Examples of the hardware changes were the addition of a flight spare condensate module to eliminate a single point failure and the addition of a liquid/gas separator in the suit cooling system.

6.3.4 AM Crew Compartment Stowage Review (CCSR) - Held at MDAC-E on 29 September - 1 October 1971

This was a flight crew review of the NASA Trainer and the AM stowage configuration just prior to shipment of the Trainer to Houston. The review included a bench review of all stowage including interfacing GFE crew equipment items. After completion of the stowage portion, crew walk-through and checkout of the NASA Trainer was accomplished. Resulting actions were handled by the RID process and included revisions to the snap and velcro locations and the crew communication units.

6.3.5 Design Certification Review (DCR) - Held at MDAC-E on 22 May 1972

The purpose of this Review was to certify the adequacy of the Airlock Module design requirements and to verify that the design was satisfactory to meet those requirements. MDAC-E assisted the NASA Program Office with the preparation of this Review to the extent of oral presentations and a data book containing information on system status, configuration and reliability of the Airlock to perform its intended mission.

No hardware or configuration impacts resulted from this review. However, additional verification testing was imposed on several items of equipment to further assure their capability to meet mission requirements.

6.3.6 AM/MDA Acceptance Review, Phase I (SAR) - Held at MDAC-E on 23-25 May 1972

This was a combined mated AM and Multiple Docking Adapter review of the systems qualification status and test data, quality configuration, and overall status of the Airlock and MDA prior to the NASA approval for continuing into Final Systems Testing.

The Review Item Discrepancies (RID's) resulting from the AM/MDA Acceptance Review, Phase I required additional documentation, and imposed additional test requirements. There were no major hardware changes and no constraints to proceed into simulated flight testing.

6.3.7 AM/MDA Acceptance Review, Phase II (SAR) - Held at MDAC-E 27-29 September 1972

The purpose of this review was to turn over the AM/MDA to NASA. It consisted of a review of the qualification status, hardware configuration, and detailed review and evaluation of the AM/MDA Final systems testing. The data package transmitted with the Airlock contained a listing of open and deferred work to be performed at KSC.

Forty-five (45) RID's were written during this review. Of this total twenty-one (21) were either closed by the board, withdrawn or disapproved. The remaining twenty-four were closed by 30 November 1972.

At this review the acceptance data package was reviewed and accepted, the NASA Form DD 250 was signed to signify formal acceptance of the Airlock by the NASA and Endorsements I and II of the Certification of Flight Worthiness (COFW) were signed.

6.3.8 Flight Readiness Reviews (FRR)

The objective of this review activity was to provide formal detailed final reviews of the KSC test program and test results to assist in assessing the flight readiness of SL-1 and SL-2 and review the hardware provided by MDAC-E for Skylab missions SL-3 and SL-4. MDAC-E provided support for the pre-FRR activities at MSFC as well as the FRR's held at KSC. The principal effort was devoted to the SL-1/SL-2 pre-FRR at MSFC on 9-10 April 1973 and the SL-1/SL-2 FRR at KSC on 18-20 April 1973. Subsequently, support was provided for the SL-3 and SL-4 pre-FRR's on 9 July 1973 and 12 October 1973 respectively and the corresponding FRR's on 12 July 1973 and 18 October 1973.

6.4 ENGINEERING REPORTS

This section identifies and briefly describes the significant Engineering documents essential to verification of all AM and supporting GSE performance/design requirements and to maintenance of configuration control. The relationship of the various verification documents is depicted in Figure 6-5.

6.4.1 AM Verification Documents

A description of the most significant validation documents is presented below:

A. Airlock General Test Plan (MDC Report H038) - The General Test Plan was the top test document; it outlined the basic philosophy and objectives of the Airlock Project test program. The plan was scoped to cover the development/qualification and acceptance test program applicable to the AM, Payload Shroud, and associated structural test articles. This document was compatible with the NASA Apollo Applications Test Requirements Document NHB 8080.3, imposed by the AM SOW, as well as the respective module development/qualification and acceptance test plans and Appendix B (testing) of the AM SOW.

B. Airlock Module Development and Qualification Test Plan (MDC Report F767) - The Development and Qualification Test Plan was a part of the basic Airlock Contract by specific reference in the basic SOW. The plan listed the specific development and Qualification tests that were imposed on the specifically identified components. This was a companion document to the Payload Shroud Development and Qualification Test Plan MDC E0041 as shown in Figure 6-5.

C. Airlock Module Acceptance Test Plan - U1 (MDC Report E914) - The AM Acceptance Test Plan was a top level document, and was a part of the Airlock Contract by specific reference in the basic SOW. It was a companion document to the Payload Shroud Acceptance Test Plan MDC E0042 as shown in Figure 6-5. The acceptance test plan defined the requirements used in verification of the subsystems of the flight article, verification of the functional interface of assigned experiments with the AM and verification of the assembled Airlock Module/Multiple Docking Adapter. This plan formulated the requirements used in preparation of SEDR test procedures.

C5

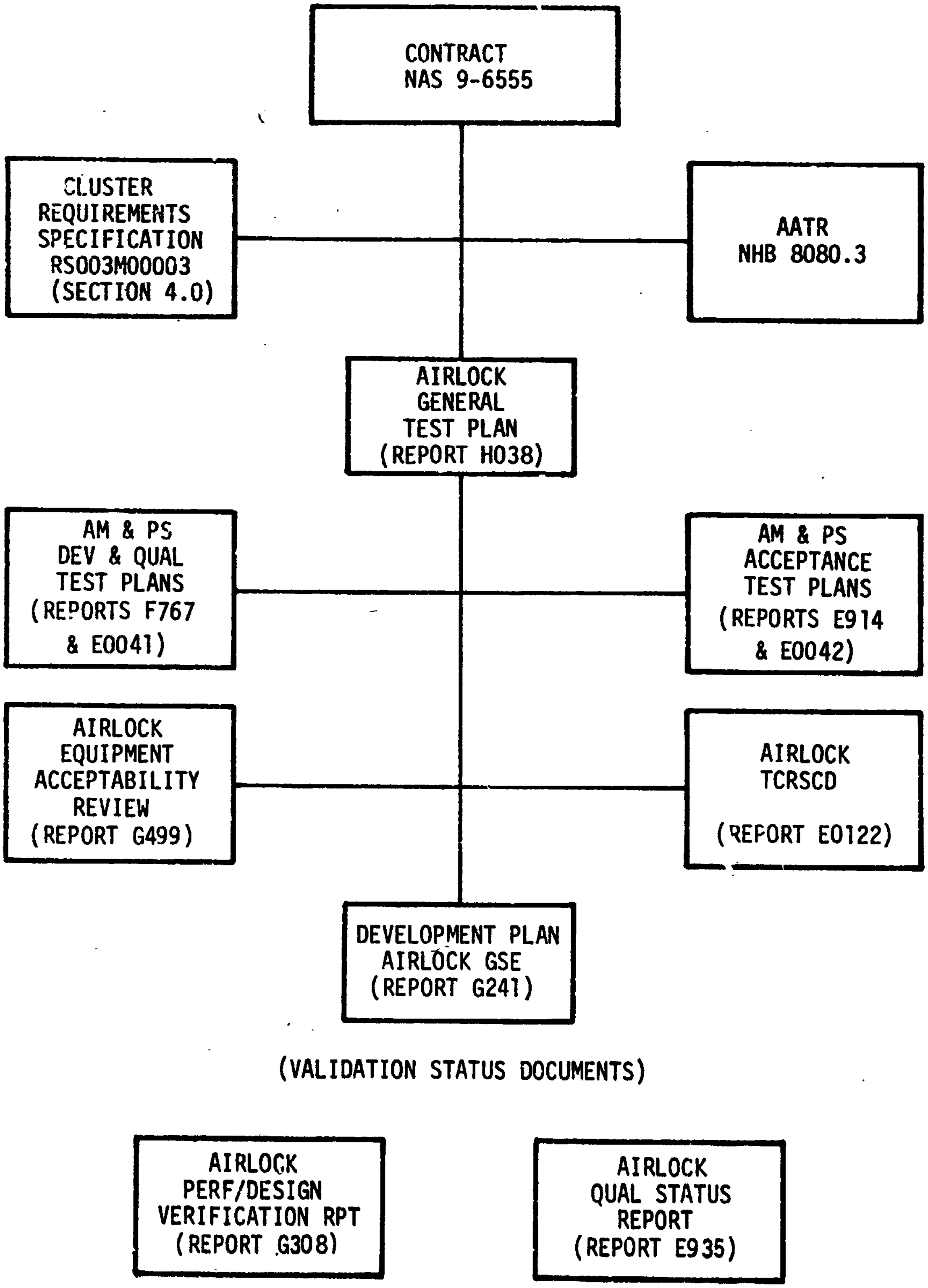


FIGURE 6-5 VERIFICATION DOCUMENTATION RELATIONSHIP

D. Airlock Equipment Acceptability Reviews (MDC Report G499) - This report documented assessed environmental levels to which all Airlock Module and Payload Shroud components were Contractor/NASA evaluated and approved. The five volume report was formulated by systems and was prepared in support of the development and qualification test program and in conjunction with a series of equipment acceptability reviews conducted with the NASA.

E. Airlock Module Test Checkout Requirements, Specification and Criteria Document (MDC Report E0122) - The contractor-prepared TCRSC defined the specific test and checkout requirements that formed the basis for KSC prelaunch test procedures. These test procedures were used to validate Airlock Module and Payload Shroud integration into the cluster.

F. Development Plan - Airlock Ground Support Equipment (MDC Report G241) - The GSE Development Plan included the definition for verification and acceptance tests performed on the GSE.

6.4.2 AM Verification Status Type Documents

The following documents provided a status of verification accomplishment:

- Airlock Performance/Design Verification (MDC Report G308)
  The Airlock Module and Payload Shroud design requirements and associated verification data were presented for the first flight article and backup flight articles in this report. Opposite each performance/design requirement appropriately cross referenced to the technical source document, the method of verification and document containing the verification data was cited.
- Airlock Module Qualification Status (MDC Report E935)
  This report documented the qualification status of all Airlock Module and Payload Shroud components on a quarterly basis.

6.4.3 Airlock Module Backup Flight Article Verification Requirements

The backup flight article verification requirements which would be performed prior to flight were identified in the MDAC-E report, Summary of Deferred Work at U-2 Delivery, provided in the backup flight article acceptance data package. Confidence level testing was performed on the backup flight vehicle in preparation for Skylab Mission Support.

6.4.4 Release Schedule

The documents described in Section 6.4 were prepared and released consistent with appropriate program milestones as defined in Appendix K (Documentation) of the Airlock SOW.

6.5 INTERFACE COORDINATION

The first Skylab Interface Control Document (ICD) was identified in 1970 and at that time, MDAC-E was selected to be custodian for twenty (20) ICD's (subsequently increased to 28). Working groups were established to develop the interface requirements; these were made up of contractor and NASA personnel that were needed to make design and technical decisions on the interfaces. Three working group meetings were scheduled for each ICD and served as development milestones. Meetings were held at the custodian's facilities, at a participating contractor's facility, and, the last one, at MSFC. NASA and its contractors each designated one interface engineer as the focal point for each ICD.

6.5.1 Baseline ICD's

The procedure used for baselining ICD's was consistent with standard contractor configuration management requirements for MSFC programs, MM 8040.12. The progress of the interface definition throughout the design/development of Skylab is shown in Figure 6-6. The original ICD's were baselined prior to or immediately following the Airlock Module Critical Design Review. During the twelve months following CDR. the majority of newly identified ICD's were developed and baselined. A few interfaces were identified very late in the program, including experiment instrumentation, equipment stowage, and AM GSE to KSC facilities.

Figure 6-7 shows the interfaces and ICD's between the AM and other flight modules and equipment. In the figure, MDAC-E ICD custodianship is identified by a heavy dot on the AM side of the interface (22 ICD's). Figure 6-8 shows those interfaces and ICD's between AM Ground Support Equipment and facilities at KSC and MDAC-E, St. Louis and again identifies MDAC-E ICD custodianship by a heavy dot on the AM side of the interface (six ICD's).

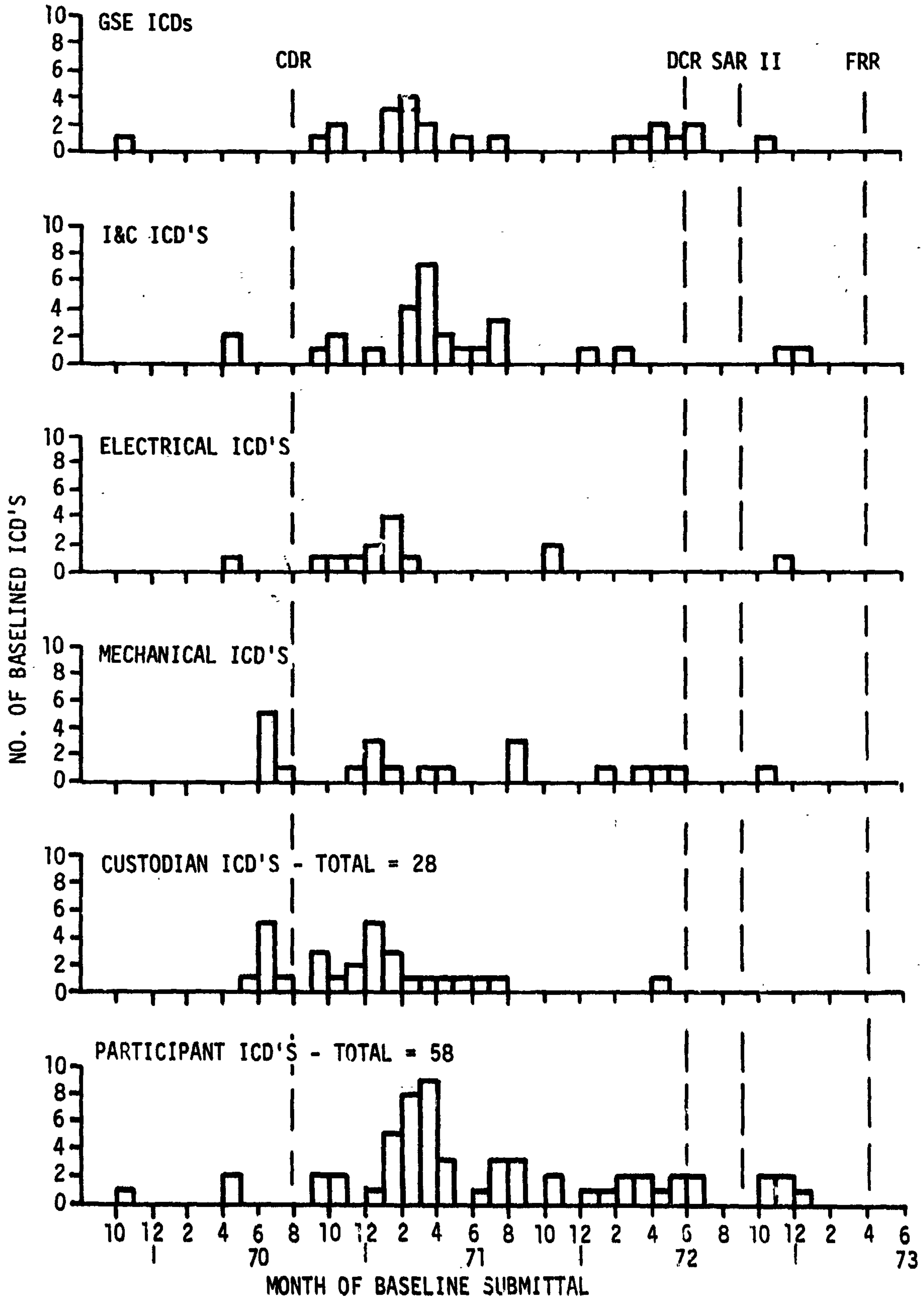


FIGURE 6-6 INTERFACE CONTROL DOCUMENT BASELINE SUBMITTALS

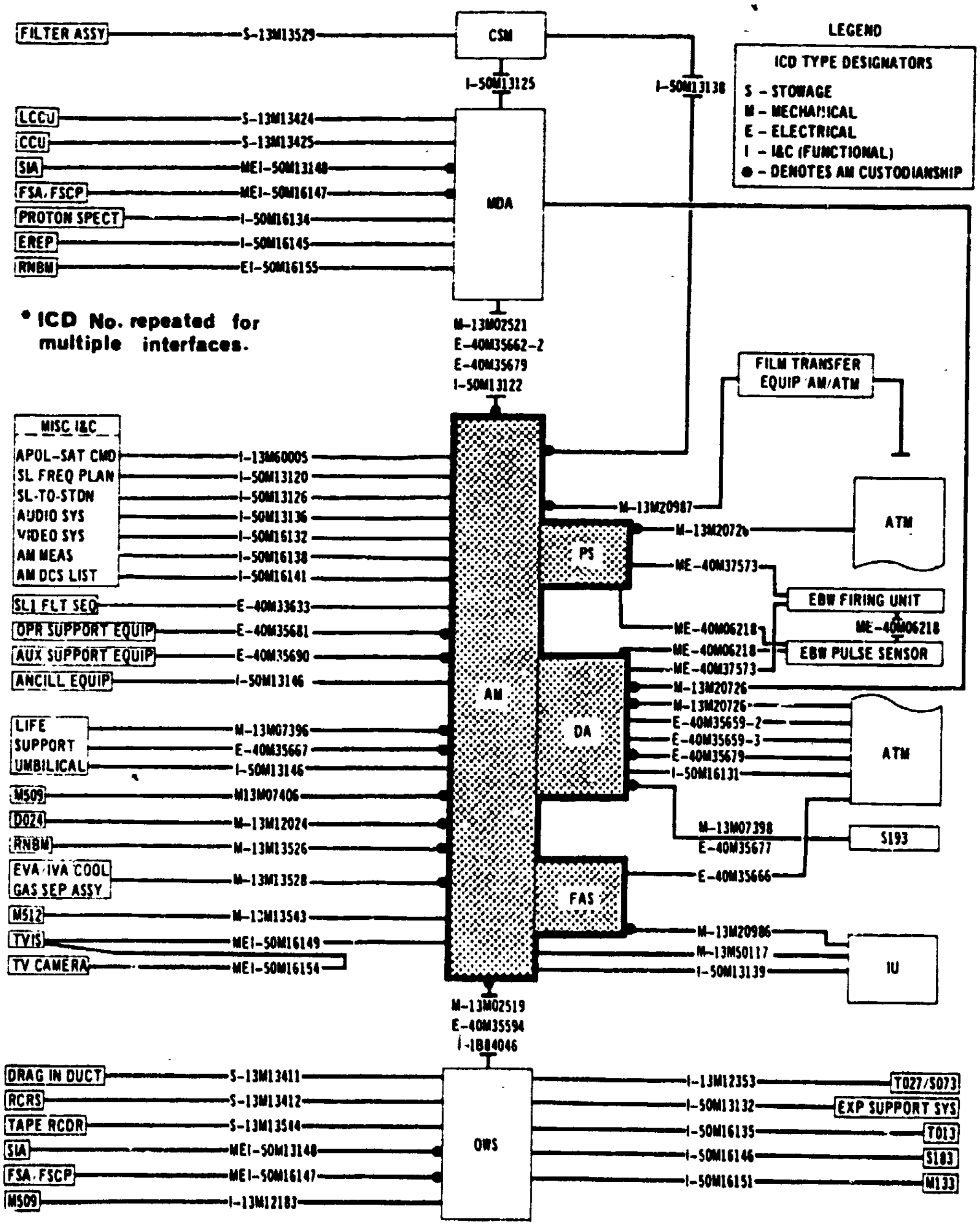


FIGURE 6-7 FLIGHT VEHICLE INTERFACES

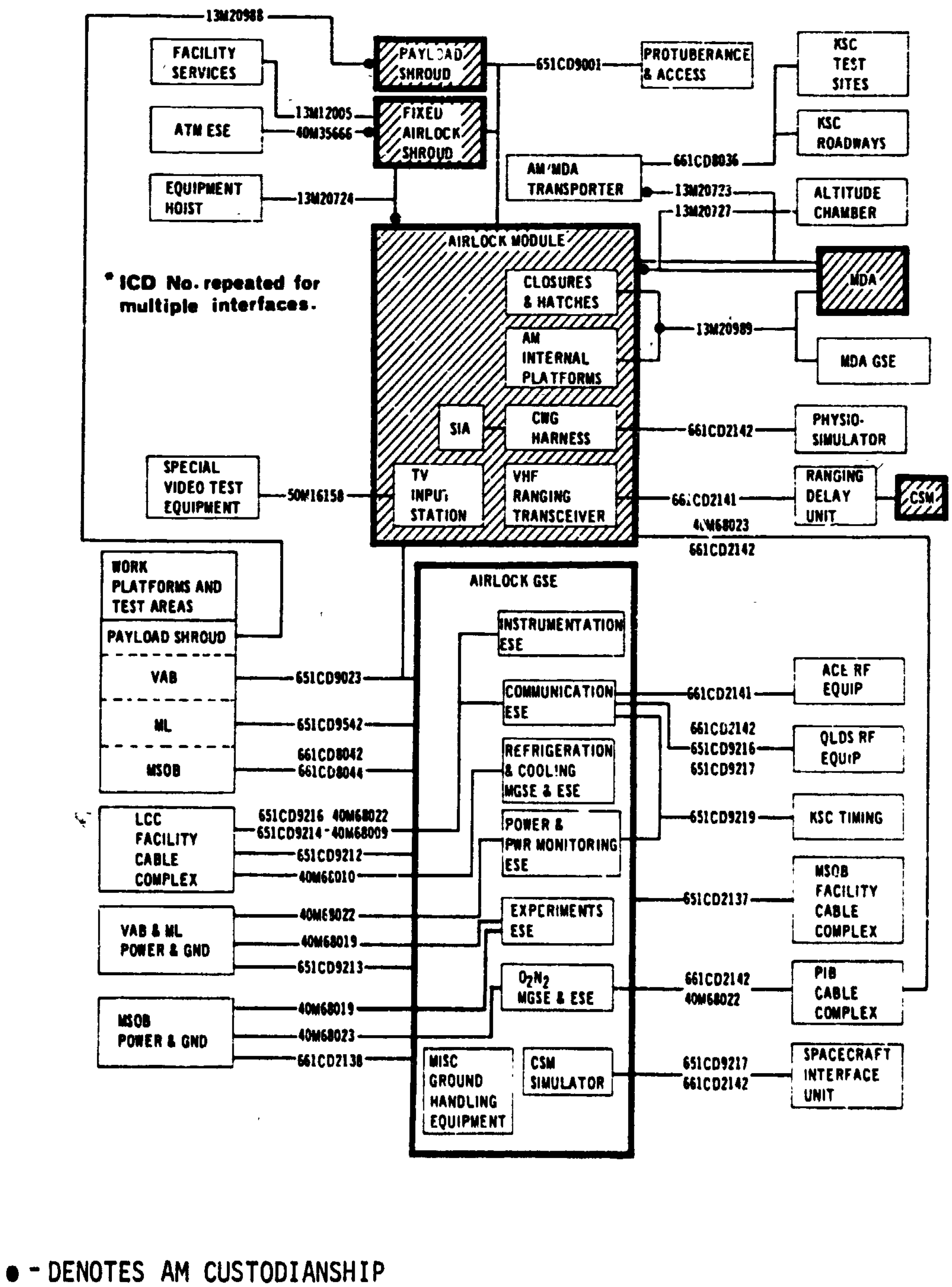


FIGURE 6-8 GSE INTERFACES

6.5.2 Interface Changes

The procedure used for defining, coordinating and submitting changes to ICD's was also consistent with MSFC requirements.

The number of ICD changes processed on a quarterly basis is shown in Figure 6-9. Concurrent with the period of baselining ICD's, the PIRN/IRN activity on the flight vehicles began to accelerate.

The increase in ICD change activity continued up to delivery because of the changes required to solidify the GSE and operational interfaces.

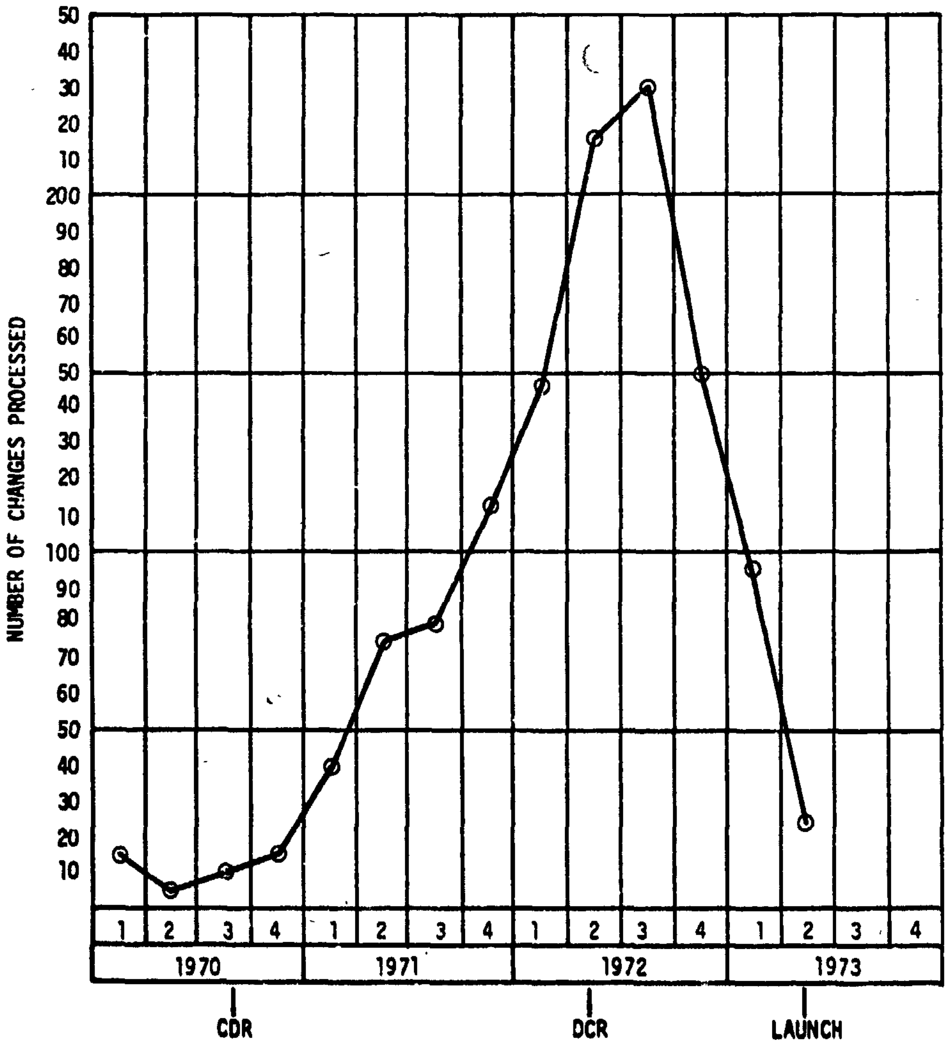


FIGURE 6-9 AIRLOCK INTERFACE CONTROL DOCUMENT CHANGE ACTIVITY

6.5.3 Interface Deviations

MDAC-E submitted four deviations to ICD requirements which are described below:

- Dimensions of ATM Truss Attachment Points - MSFC initiated DDA-1 to ICD 13M20726A to document an out-of-tolerance condition on the ATM involving the interface with the Payload Shroud S/N 000003 resulting from MRD AP 3603. The departure was acceptable to MDAC-E since the dimensions were within the adjustment range of the Payload Shroud interface hardware.
- Mislocated Access Opening in Payload Shroud - MDAC-E submitted DDA-1R1 to 65ICD9001 to redefine one of the Payload Shroud S/N 000003 access openings for the electrical interface connection in Quadrant IV due to mislocation during manufacture. The cover for the opening was reworked to accommodate the lengthened opening.
- Resistance of Payload Shroud EBW Trigger Circuit Wiring - MDAC-E submitted DDA-1 to ICD 40M3753 to allow a resistance of 1.2 ohms as the EBW trigger circuit resistance for the Airlock Module and Payload Shroud instead of the specified 1.0 ohm. MDAC-E's analysis indicated sufficient margin existed at minimum AM bus voltage and a circuit resistance of 1.2 ohm to provide satisfactory operation.
- Wiring to ATM Power Feeders - ICD 40M35659-3 specified the requirement for twisted wiring connecting the ATM bus with the AM bus. Since the ICD 40M35659-3 was submitted to MDAC-E for contractual incorporation after the ATM power feeder detail design was completed, MDAC-E submitted Deviation Approval Request (DAR) MDAC-E-1 to permit this deviated condition. The cost and schedule impact attendant to modification of the design was not considered warranted by the theoretical benefits of twisted wires.

6.5.4 AM/OWS Integration

Whereas the Airlock was supplied by MDAC-E, the Orbital Workshop was supplied by MDAC-W and was managed by a separate NASA Program Office. In order to maximize the use of company resources and have the assurance that both vehicles would "play together," an integration office was designated these responsibilities. The initial activity concentrated on conflicting or incomplete requirements. Typical requirements in this category were:

- Both the AM and OWS were providing a complete Caution and Warning System.
- Neither the AM or OWS included provisions to service the life support umbilicals and AM water systems.
- Electrical requirements for operation of MDA vent valves, meteoroid shield deploy, SAS deploy and TACS were not consistent between the AM and OWS
- A means for pressurizing the OWS water tanks was not defined.

Several programmatic changes were the basis for another group of integration activities. Typical of these problems were:

- Stowage of spare tape recorders in the AM or OWS.
- Stowage of a spare condensate module in the AM or OWS.
- Additional trash bags in the OWS and the effects on cluster dew point build-up.
- Condensate transfer to the OWS for primary overboard dumping.
- Performance of the AM environmental control system for a 50° orbit inclination.

Expeditious resolution to these problems was accomplished by parallel trade studies and MDAC-E/MDAC-W integration meetings.

The AM and OWS were scheduled for mating four months prior to launch. Therefore, it was necessary to assure that mating and integrated system testing at KSC would not be delayed by discrepant interface conditions. To this end, a positive interface verification program was established. The first action taken was to have MDAC-W review AM production drawings and MDAC-E review OWS production drawings. Several discrepancies were found and the necessary changes were incorporated. To assure that the functional systems were compatible these additional actions were taken:

- Design review of the integrated environmental control system.
- System analysis of the instrumentation and communication system.
- System analysis of electrical power distribution and control.

Result of the joint MDAC-E/W effort was an AM/OWS integration without discrepancy.

6.5.5 Interface Verification

Interface verification at St. Louis was performed through analysis, quality assurance, and systems testing of the mated Airlock and Multiple Docking Adapter and was necessary to identify discrepancies prior to shipment. Prior to the mating of the AM/MDA at the MDAC-E facility in St. Louis, a detailed review of the various test procedures was made to confirm that all interfaces requiring test verification would be covered.

All test results at KSC were monitored for possible impact upon interface verification and documentation. During interface verification testing a grounding discrepancy on ECS ducts between the AM and MDA was found and remedied by grounding the AM side of these ducts. Also two temperature measurements were found to be interchanged during testing of instrumentation and telemetry in the O&C test. This was corrected on U1 by changing the requirements of the IP&CL and AM measurements list and on U2 the measurement wires were interchanged to make them meet the revised assignments. Effective interface control was responsible for the very few verification problems encountered during integrated testing.

The detailed review of all flight anomalies determined that no anomalies were caused by incorrect or incomplete interface requirements.

6.6 CONFIGURATION MANAGEMENT

6.6.1 Requirements

Airlock Project configuration management requirements were defined in Appendix J to the Statement of Work and supplemented by additional requirements pertinent to Ground Support Equipment (GSE) in Appendix E. These appendices established requirements for:

A. Documenting Airlock and Payload Shroud performance requirements and configuration by CEI type specifications and documenting GSE requirements by a GSE Index.

B. Processing and documenting changes to the performance and configuration parameters utilizing a formal change control and reporting system employing the ECP to submit Class I engineering changes for NASA approval.

C. Submitting periodic status accounting reports summarizing the effect of approved changes on project status; accomplished through development and periodic submittal of a Configuration Status Accounting Report and periodic updates of the CEI specifications.

D. Providing documentation to support Airlock and Payload Shroud acceptance by NASA.

MDAC-E was also required to participate in special procedures to control changes to the KSC test and checkout requirements and stowage requirements after delivery of the first AM/MDA flight article. The KSC Test and Checkout requirements for the AM/MDA were documented in MDC Report E0122 while the Airlock stowage requirements were documented in the NASA document I-SL-006.

6.6.2 Configuration Identification

Technical requirements for the U1 flight hardware were identified in CEI specifications and other technical documentation as listed in Figure 6-10. These requirements evolved progressively as a result of detailed analyses and testing or resulted from direction received at subsystem meetings, design and program reviews, and contract change orders. This technical documentation established the flight article requirements baseline. Changes to these documented requirements were classified as Class I engineering changes and required NASA approval.

GSE requirements were identified in a master index that also evolved progressively: first, as the St. Louis Integrated AM/MDA System Test requirements developed through meetings with the NASA and other contractors responsible for furnishing hardware such as EREP and then as the KSC test and checkout requirements became finalized. Changes such as additions, deletions, or modification to all GSE were processed as Class I engineering changes and similarly required NASA approval.

DOCUMENT NO.	DOCUMENT TITLE	SUBMITTAL SCHEDULE	METHOD OF REVISION
E946	AIRLOCK CEI SPECIFICATION	AS REQUIRED	SCN/ECP
E946 ATTACHMENT 1	AIRLOCK CONFIGURATION LIST (ECL)	AS REQUIRED	DOCUMENTATION REVISION
MDC E0047 PART I	PAYLOAD SHROUD CEI SPECIFICATION PART I	AS REQUIRED	SCN/ECP
MDC E0047 PART II	PAYLOAD SHROUD CEI SPECIFICATION PART II	AS REQUIRED	SCN/ECP
MDC E0047 PART II ATTACH. 1	PAYLOAD SHROUD CONFIGURATION LIST	AS REQUIRED	DOCUMENTATION REVISION
40M35622	AIRLOCK POWER ALLOCATION DOCUMENT	AS REQUIRED	SCN/ECP
I-SL-006	AIRLOCK MODULE STOWAGE LIST	AS REQUIRED	SLCN/ECP
ICD'S	INTERFACE CONTROL DOCUMENTS	AS REQUIRED	IRN/ECP

FIGURE 6-10 TECHNICAL REQUIREMENTS DOCUMENTATION

CEI specifications were prepared for the Airlock Module (AM) and the Payload Shroud (PS) to define performance and design requirements. These specifications were identified as MDC Report E946 for the AM and MDC Report E0047 for the PS. The requirements in the CEI specifications were organized by Airlock systems in

accordance with the Statement of Work requirements. The specific performance and design requirements were either specified directly or by reference to other design requirement sources such as the Interface Control Documents (ICD's), Interface Definition Documents (IDD's), applicable NASA Publications including AM Stowage List, 1-SL-006, and Flammability, Odor, and Toxicity Requirements, etc., MSFC-SPEC-101A and MDC design and process specifications and drawings. The AM CEI specification was originated early in the program and was updated in late 1969 to define the "dry" configuration requirements. This specification, in conjunction with the referenced technical documentation established the baseline requirements for design and development of the Airlock Module, including the Fixed Airlock Shroud and ATM deployment assembly. The PS CEI specification originated in 1969 when the change to the "dry" configuration required a new aerodynamic launch shroud.

As the requirements were expanded or altered, the specifications and applicable technical documentation were updated by Specification Change Notices (SCN) or equivalent change paper to insure a continuing accurate identification of the requirements. In addition to design requirements, the CEI Specifications for the flight articles included the Engineering Configuration Lists (ECL) which identified the hardware configuration by both a system and an indentured breakdown, from the top assembly to the "black box"/component level. The ECL's were systematically reconciled with the As Built Configuration Lists (ABCL's) to verify the configurations. All incompatibilities were resolved on an individual basis. The ECL's became part of their respective CEI's by ECP action at time of delivery.

The Ground Support Equipment (GSE) required to assemble, test, and checkout the AM and PS was identified in the GSE Index, 61E000001, which contained a listing of the equipment end items by Part Number. The GSE Index was organized by functional groups such as Ground Handling Equipment, Ground Test Equipment, ECS Support Equipment, Electrical System, etc., and contained a functional description and allocated usage of the equipment. The Index was updated periodically to incorporate the GSE changes resulting from approved engineering changes. GSE Index change forms were issued to accomplish the updating, as a separate revision to the GSE Index. These revisions were submitted by contracts letter to provide MSFC with an up-to-date identification of the GSE baseline.

The cluster performance and design integration requirements for the Skylab Program were defined in the Cluster Requirements Specification (CRS) with the purpose of ensuring that all hardware would successfully function as an integrated system to accomplish Skylab mission objectives. The CRS was imposed on the AM as a guideline document only. MDAC-E reviewed the CRS and all subsequent change packages for compatibility with the Airlock Module, Payload Shroud, and associated GSE technical baseline. Differences in technical baseline requirements were transmitted, with substantiation, to NASA for appropriate disposition.

6.6.3 Configuration Change Control

Engineering changes to the Airlock Module and Payload Shroud hardware were classified as Class I or Class II. Changes identified as Class I were controlled by the NASA (MSFC) by approval of ECP's. Class I changes encompassed the following:

- New requirements to Airlock, Payload Shroud, and GSE hardware.
- Hardware changes resulting from additional performance requirements allocated to the Airlock Module or from different environmental requirements.
- Changes to interface requirements as defined in Interface Control Documents (ICD's) or definition of interface requirements by formally accepting baselined ICD's.
- Changes to crew station arrangement displays, and controls.

Most of the Class I changes occurring on the Airlock and Payload Shroud projects were initiated in response to interface changes or to NASA direction either by response to contractual change orders or from actions assigned at crew and subsystem meetings. The interface changes were controlled by the NASA subsystem manager responsible for the particular functional area such as Instrumentation and Communications, Electrical, etc.

Class II changes, which did not require submittal of ECP's, were controlled by the MDAC-E Change Control Board (CCB). Although Class II changes did not require NASA approval, copies of these changes were submitted for NASA review.

All changes to flight hardware after delivery to KSC were Class I and required NASA (MSFC) approval of ECP's.

Contract changes other than engineering changes were controlled by the submittal of a Contract Change Proposal (CCP). CCP's covered changes affecting trainers furnished by MDAC-E, testing, general support activities, and schedule adjustments.

The system used by MDAC-E to respond to customer-initiated changes is depicted in Figure 6-11. Engineering prepared the detailed Technical Descriptions (TD) for Class I engineering changes to establish a complete and comprehensive technical definition of the change for MSFC evaluation. The ECP TD's were forwarded to Cost Estimating and Contracts for formal cost and schedule analysis. Changes to technical baseline documentation such as the CEI Specification (E946), Stowage List, and Interface Control Documents (ICD's) were included as part of the ECP. Formal cost estimates were initiated through the release of a Request for Estimate (RE). As illustrated, the ECP Technical Description was combined with the associated cost exhibit (ROM) by Airlock Contracts to form the complete change package which, after approval by engineering and program management, was forwarded to MSFC through the MDAC-E Huntsville office. Normal response time for ECP submittals was 35 days and firm cost and delivery proposals were submitted within 65 days from the date of a change order.

During the latter stages of Spacecraft System testing at St. Louis and during KSC assembly and testing, incorporation of changes became time critical because of the potential effect on Airlock Module delivery and Skylab launch schedule. Under these conditions, it was necessary to expedite the submittal of ECP's to provide both MSFC and KSC with a definition of the hardware change so that effective implementation planning could be accomplished to avoid schedule delays. MSFC established a project office at KSC to monitor the KSC checkout operations and be able to provide on-the-spot direction to MDAC-E. The TWX ECP was used to provide this technical information complete with a Rough Order Magnitude (ROM) estimate to both MSFC and KSC for decision making. The TWX ECP was prepared by Engineering in response to the expedited action request, coordinated and approved by engineering and program management, and transmitted to MSFC and KSC. Because of this urgency to implement approved changes in the Flight Article and associated GSE at KSC, a "dedicated shipping team" was organized to expedite the delivery of modification kit hardware complete with modification instructions to KSC. This insured that modification hardware was available when required.

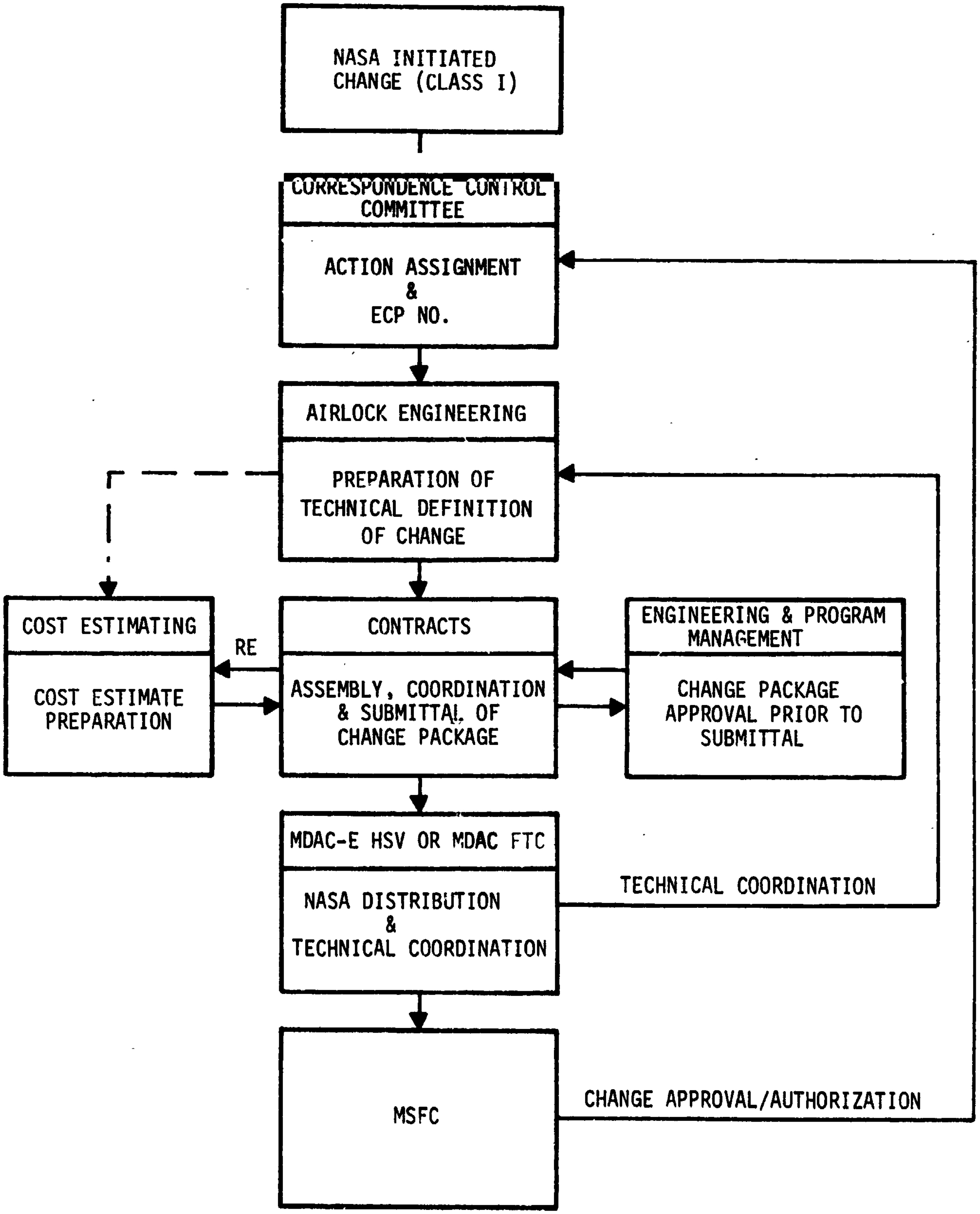


FIGURE 6-11 CLASS I CHANGE FLOW PLAN

6.6.3.2 NASA Coordination

After submittal of ECP's, Airlock engineering functioned as the point of contact for coordination of technical changes to ECP's desired by MSFC. Working through the MDAC-E Huntsville and the MDAC - Florida Test Center (FTC) Offices, the status of submitted ECP's was continually monitored by Engineering to insure that changes were implemented in accordance with NASA requirements.

The MDAC-E Huntsville office was responsible for the technical cooridnation within MSFC. Subsystem engineers assigned to MDAC-E Huntsville performed this function with the MSFC laboratories and the Airlock Module Project Office. Change proposal discrepancies were resolved through coordination with St. Louis and changes fed back for evaluation prior to Level II or Level III CCB action. The MDAC-FTC office performed a similar function within KSC and fed back implementation changes for evaluation by MDAC-E. During the critical period of KSC checkout, MDAC-E provided direct technical support for the MSFC project office at KSC to assist in resolving discrepancies that occurred prior to launch. Changes initiated by KSC as a result of Discrepancy Reports (DR's) and which required update engineering were coordinated with St. Louis prior to CCB action. Engineering issued by the MDAC-FTC operations to clear these DR's was received by MDAC-E, reviewed for impact on the backup flight article, trainers, and St. Louis GSE, and approved by the MDAC-E CCB. Subsequently the engineering was released to maintain compatibility between the backup equipment and the flight article and associated GSE. In such cases, ECP's were prepared and submitted to MSFC for disposition. The coordination was particularly effective during the final stages of KSC checkout prior to the Flight Readiness Review when ECP's were processed and submitted within 24 hours after resolution of the discrepancies. Close coordination with MDAC-FTC was also maintained during the subsequent crew launches to insure that the stowage hardware required for the manned flights was identified in ECP's and was shipped to KSC within the scheduled time.

6.6.3.3 Significant Changes

Contractual changes processed during the program can be grouped into one or more of five categories as described below. A total of 1462 ECP's and CCP's (including expedited ECP's) were processed during the program, spanning the period from September 1969 through April 1974.

A. Feasibility or Impact Assessment Studies - One of the most significant ECP's in this category was ECP-092 submitted in response to MSFC direction to conduct a survey to determine the impact of complying with MSFC-SPEC-101A requirements. The ECP proposed to conduct a survey of the Contractor Furnished Equipment (CFE) materials to evaluate compliance with MSFC material requirements. The evaluation consisted of determining if the materials complied with the applicable flammability, odor, off-gassing, and oxygen compatibility criteria of MSFC-SPEC-101A, Amendment 1. This change included the effort of listing and evaluating all CFE materials used in:

(1) The AM flight vehicle pressurized compartment.

(2) The AM oxygen supply system components.

(3) GSE utilized in the pressurized compartment of the AM/MDA during the manned SST.

(4) The flight vehicle external to the pressurized compartment and in direct line-of-sight to critical sensors or optical surfaces.

(5) GSE required for servicing AM Gaseous oxygen system.

Specific hardware changes resulting from this survey were proposed under separate ECP's.

B. Hardware Changes - ECP's submitted during the program which were classified as hardware changes resulted from additional functional requirements, or from additional environmental requirements imposed by the NASA. As the design progressed, additional capabilities were authorized for incorporation into the Airlock Module, and existing design requirements were changed to improve the operational capability of the Skylab. An example of the latter is the change directed by MSFC authorizing MDAC-E to provide a minimum dewpoint of 46°F for the Saturn Workshop (identified as ECP 278). This change was initially discussed and authorized in late 1970 and simultaneously, a series of meetings were held on the subject

of battery life improvements by maintaining lower battery temperatures. In developing the cooling system changes required to achieve the 46°F dewpoint, it was concluded that additional cooling for the batteries could be provided with less impact if incorporated concurrent with the dewpoint change. Concepts were developed and presented to MSFC in 1971 and direction was received to proceed with the integrated design configuration that provided the greatest benefit to the batteries. This ECP resulted in significant changes to the coolant system design by creating a Suit/Battery Cooling Module and by rerouting coolant lines.

C. Test Requirements Changes - The most significant change in this category was ECP 071 which resulted from the imposition of more severe environmental test requirements on Airlock Module equipment. The additional test criteria, directed by MSFC as a result of the Equipment Acceptability Reviews, caused additional testing, procurement of additional test specimens, and added analysis in order to verify qualification to the changed environments. This change encompassed test changes (including test hardware) to the Airlock Communication, Instrumentation, Electrical, Structural/Mechanical and Environmental Control Systems. Hardware changes resulting from failures during the tests were authorized by approval of a separate ECP. For example, failures occurred on three mechanical assemblies such that redesign and retesting was required to meet the more severe environment. These hardware changes were authorized by MSFC and defined in ECP 478.

D. Documentation Type Changes - Documentation type changes submitted during the program included interface changes, specification, stowage list, and critical item list changes. The interface changes were most significant primarily because of the large effort necessary for evaluation of the quantity of changes.

E. Training/Simulation Equipment and Support Changes - Changes grouped in this category consisted of amendments to training and mission simulation equipment, and mission operations support requirements. One of the most significant changes to mission simulation requirements was defined in CCP 171 and CCP 172. CCP 171 was concerned with putting together breadboard installations of the Instrumentation and Communication systems to form a Skylab Test Unit (STU). This unit was used for compatibility testing of the U1 and for simulation of mission discrepancies and anomalies. The STU was expanded to include the capability to function as a tracking site and obtain telemetry data directly from the Skylab. Similarly, CCP 172 was concerned with providing a Skylab Test Unit for the Environmental Control System (ECS) and Thermal Control System (TCS). This STU was used to support the investigation of mission anomalies and discrepancies such as the thermal problem associated with loss of the OWS meteoroid shield during the launching of SL-1. One of the significant changes involving mission support was CCP 151 submitted in response to MSFC authorization to expand the level of effort for mission support. This expansion was made necessary to provide more effective support to the MSFC mission support activity.

6.6.4 Configuration Status Accounting

Documentation of the configuration status for the Airlock Module and Payload Shroud was accomplished by preparation of MDC Report E0469, Airlock Configuration Status Accounting Report, and by preparation of Specification Change Notice (SCN's) to the CEI Specifications, MDC Reports E946 and E0047.

The Configuration Status Accounting Report, MDC Report E0469, was formalized and baselined at the time of U1 delivery and was maintained through to program completion. The report contained a status of all change proposals processed during the program, and all waivers and deviations applicable to the Airlock Module, Payload Shroud, and associated GSE. Special status data for each change included the identity of the CEI affected, change period, change status, and approval reference. This provided MSFC with the capability to identify both the

"approved configuration" and "current configuration" as the flight article and associated GSE proceeded through assembly and checkout at KSC.

In addition to the MDC Report E0469, MDAC-E also prepared and maintained MDC Report E0578, Planned Work at KSC, U1 Flight Hardware and Associated GSE. This report was prepared prior to the acceptance and delivery of the U1 flight hardware (AM and PS) and identified the deferred and open work authorized by the customer to be performed at KSC on U1 flight hardware and associated GSE. The status of this work as well as modification kit installation status was monitored closely, and informal status reports were prepared to provide visibility for MDAC-E Eningeering and Program Management. These were also made available to MSFC on an informal basis. The MDAC-E (ATLO) Report, Summary of Deferred Work at Time of U-2 Shipment, is a similar document for the backup vehicle.

SECTION 7 MISSION OPERATIONS SUPPORT

The Airlock Project/Skylab mission was unique in comparison to previous manned space programs. Previous programs involved a series of flight test vehicles before major operational missions were launched. The first Airlock Module, as well as the complete Skylab vehicle, was completely operational at first launch.

In view of the lack of flight-test experience, extensive real time system monitoring and evaluation was implemented by MSFC and supported by MDAC-E. Support was provided by technical personnel on-site at Huntsville, backed up by the Airlock Engineering organization in St. Louis. In addition to the technical personnel, extensive system simulation Spacecraft Test Units (STU's) and Computer Simulations were established. The Airlock backup unit (U-2) with the MDA was also configured to provide support with system tests.

The Mission Support provided to the Skylab Program by MDAC-E proved to be effective in monitoring Airlock system status and in establishing workaround procedures for those system discrepancies which did occur.

7.1 MISSION OPERATIONS PLAN

Mission operations experience during Projects Mercury and Gemini provided insight to the dynamic nature of real time flight plan changes, support required to diagnose hardware discrepancies and, as the programs matured, development of plans for extending mission duration and utilizing system capabilities which proved to be greater than initially considered. This experience emphasized the importance that MDAC-E Mission Operations Support would be to the Skylab Mission in view of the fact that all basic SWS "housekeeping" systems were in the Airlock and in view of the lack of flight test data on this vehicle configuration.

In order to implement organizations and procedures which would support and complement the MSFC functions, Airlock personnel supported many planning meetings and informal discussions with cognizant MSFC personnel in the Airlock Project Office, Mission Operations, Astrionics, Astronautics and Computation Laboratories. By January 1972, plans had developed sufficiently for the Airlock Project to designate a Mission Operations Manager, charged with the responsibility of identifying support functions and insuring that necessary and adequate support was provided to MSFC. During the following months, MDAC-E assigned personnel to the on-site Huntsville teams that would provide direct support, in each discipline, to the MSFC Astronautics and Astrionics Laboratories and coordination within the Hurtsville Operations Support Center (HOSC).

Beginning early in 1972, MDAC-E also developed the St. Louis Skylab Communication Center facility, and Skylab Test Units for I&C and ECS system simulations, defined mission data requirements, and developed or revised software programs to assist in system analysis and data reduction.

After delivery of the Airlock to KSC, the personnel locator service was instituted within the Comm Center.

Three planning documents outline the details of the MDAC-E Mission Operations Support effort for Skylab.

- Airlock Mission Operations Support Plan, dated 12 February 1973.
- Airlock Mission Support Hardware Plan, MDC Report E0571, dated 20 April 1973.
- Airlock Mission Support Software Plan, MDC Report E0723, dated 8 December 1972.

7.2 MISSION SUPPORT ORGANIZATION

Airlock Mission Operations Support was implemented in a manner to make maximum use of Airlock engineering and Acceptance Test and Launch Operations (ATLO) organization as it existed through the Airlock hardware design and development phase, as opposed to assigning selected personnel from these organizations to a separate mission operations group. All personnel within these organizations time-shared Mission Operations Support with the routine sustaining engineering effort. This existing organization provided the most complete and authoritative source of design and operational experience. This background experience was invaluable in diagnosing discrepancies in Airlock systems, recommending troubleshooting procedures, and designing fixes to be implemented by the flight crew.

The assigned Mission Operations Manager was responsible to MDAC-E and NASA management in all matters pertaining to MSFC Mission Operations Support. His primary function was to plan, organize, and control the effort of assigned engineering personnel to accomplish assigned tasks in a timely manner. He was assisted by a staff with the following responsibilities:

Evaluation and Operations Coordination

- Coordination of Airlock systems evaluation and support to flight operations.
- Definition and planning of evaluation and operations scope, facilities, tasks and data.

Mission Operations Design Support

- Performance of Airlock systems malfunction analysis.
- Review of Flight and Launch Mission Rules.
- Summarization of hardware discrepancies experienced in flight.

Mission and Flight Planning

- Validation of mission and flight planning documentation.
- Support of MFP studies as requested by MSFC.

On-Site Operations Support Coordination

- Performance of systems assessment and problem solving as necessary during pre-mission KSC testing, mission simulation and manned and unmanned orbital operations.
- Participation in pre-mission definition and planning of evaluation and operations activity in coordination with Evaluation and Operations Coordination Group Leader.

Mission Support involving 24 hours/day activity with actions assigned and responses requested within hours of assignment dictated special handling and working relationships among all participants. Requirements for time critical turnaround on Action Requests (AR's), necessitated detailed performance of tasks to be normally accomplished by working level engineering group representatives within the cognizant project engineering groups. These engineering group representatives served as the primary contact within their respective group for technical support. These personnel were responsible to their engineering group management for the technical accuracy of their support effort and responsible to the Mission Operations Manager for schedule, priority, format and content of Mission Operations requirement responses.

Figure 7-1 illustrates how this flow of responsibilities and communication took place at the working level for representative groups.

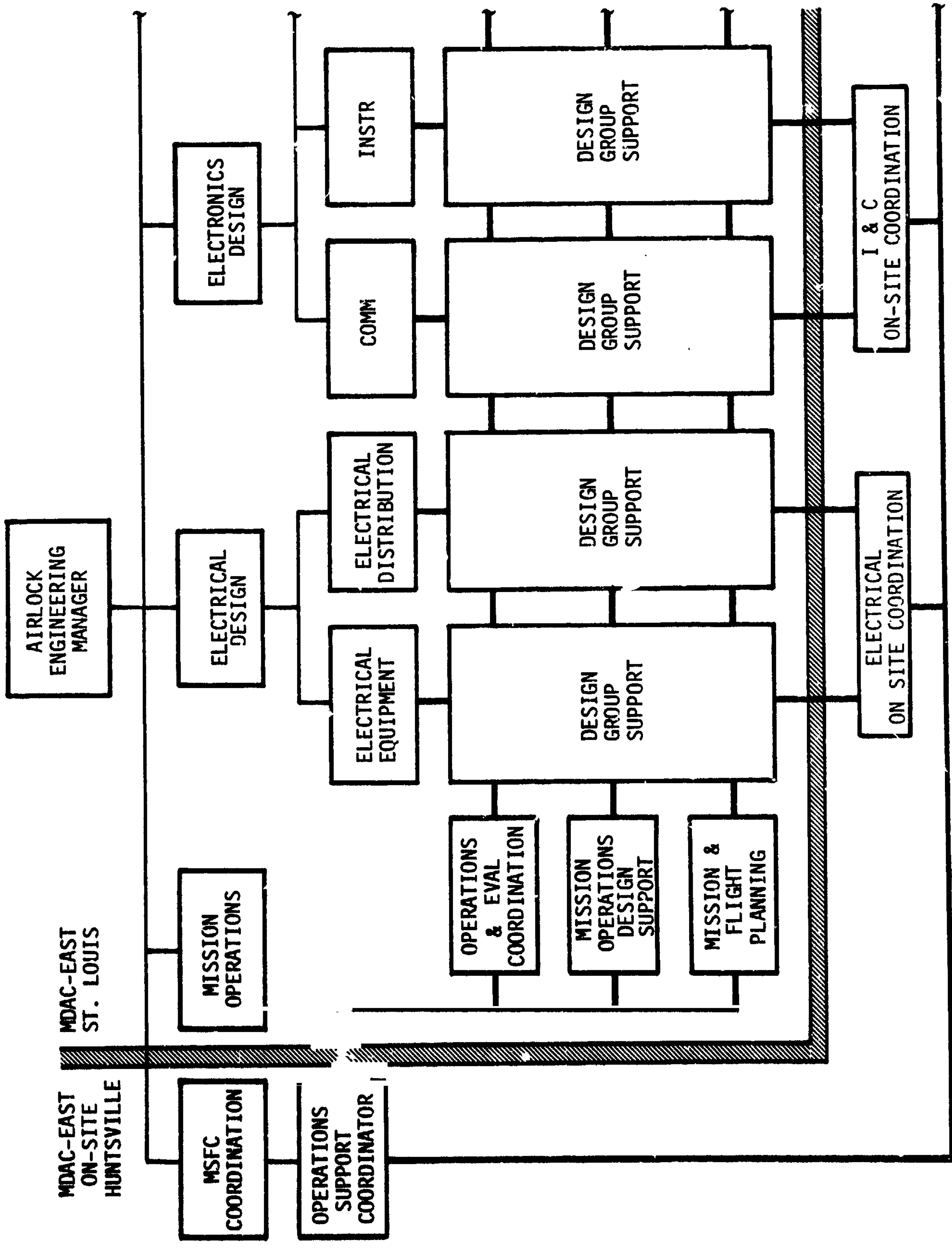


FIGURE 7-1 EXAMPLE AIRLOCK PROJECT MISSION COMMUNICATIONS AND RESPONSIBILITIES (AM DESIGN AND TECHNICAL GROUPS)

7.3 MISSION SUPPORT FACILITIES

7.3.1 Communication Center

MDAC-E maintained and staffed a communications facility (Comm Center) in St. Louis. This facility, located in Bldg. 106, Level 2, served as the central location for rapid data and information transmittal and for personnel locator activities; it was the focal point for St. Louis Mission Support activities. Figure 7-2 depicts the physical layout of the Comm Center. Figures 7-3 and 7-4 are photographs of typical system trend charts maintained in the Comm Center. The general features of the Comm Center were as follows:

- All up readiness - 14 August 1972.
- Location - Building 106, Room 292.
- Size - Seventy feet by thirty feet.
- Security protection.
  - Sound proof.
  - Door lock(s).
- General Work Area
  - Mission Operations Manager
  - Operations and Evaluation Coordination Group
  - Mission Operations Design Support Group
  - Mission and Flight Planning Group
  - Locator and Access Control Desk
  - Conference/Work Tables
  - Wall Charts
    - System Trend Charts
    - System Schematics
    - Consumables Status
    - Telemetry Data Tabs from STU/STDN
    - NASA Mission Reports
    - Action Requests and Responses
- Communications Room
  - Mission Data table or console and chairs.
    - GOSS Speakers (2).
    - Writing space and stationery storage.
    - Voice tape recorder and playback (2).

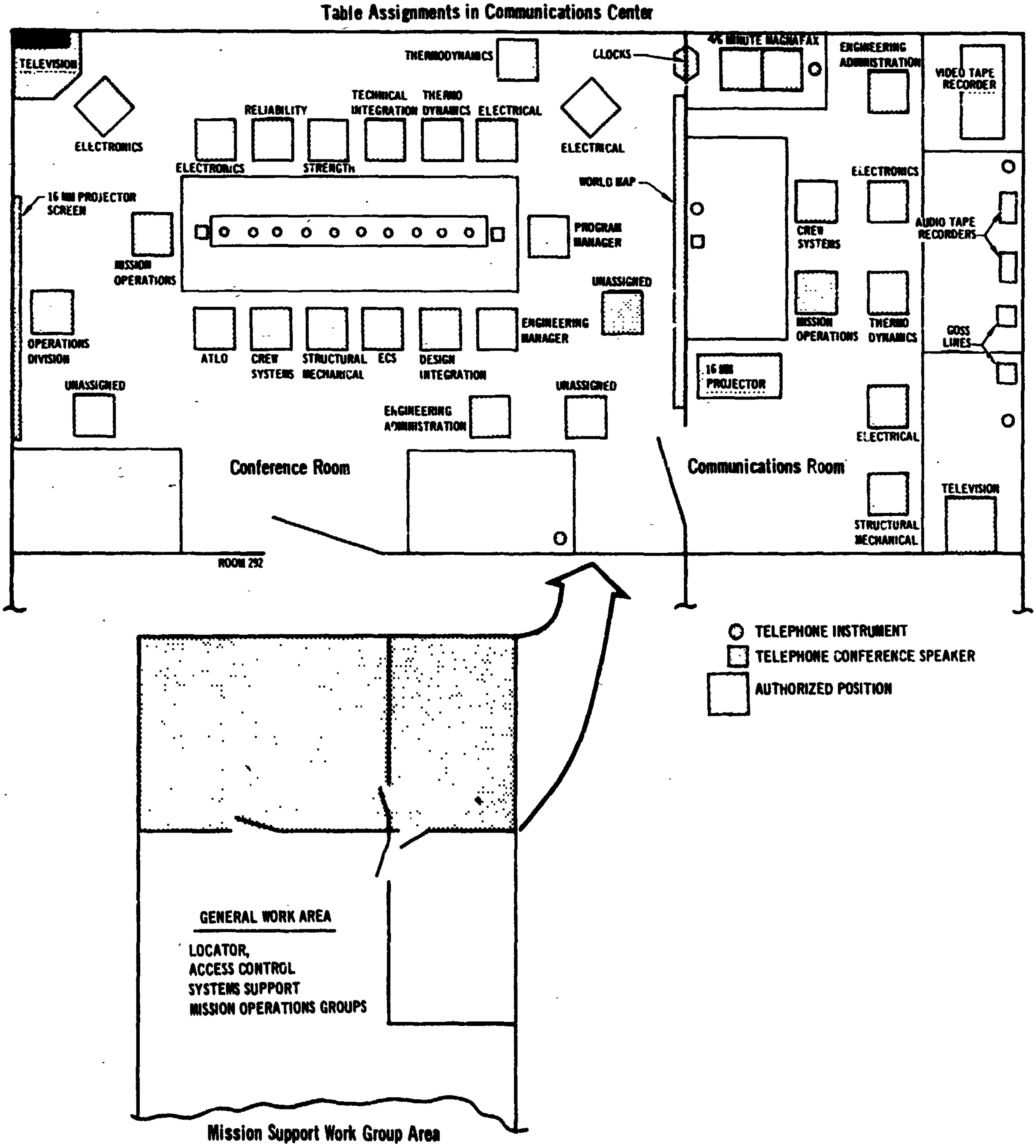


FIGURE 7-2 MDAC-E MISSION OPERATIONS COMMUNICATIONS FACILITY

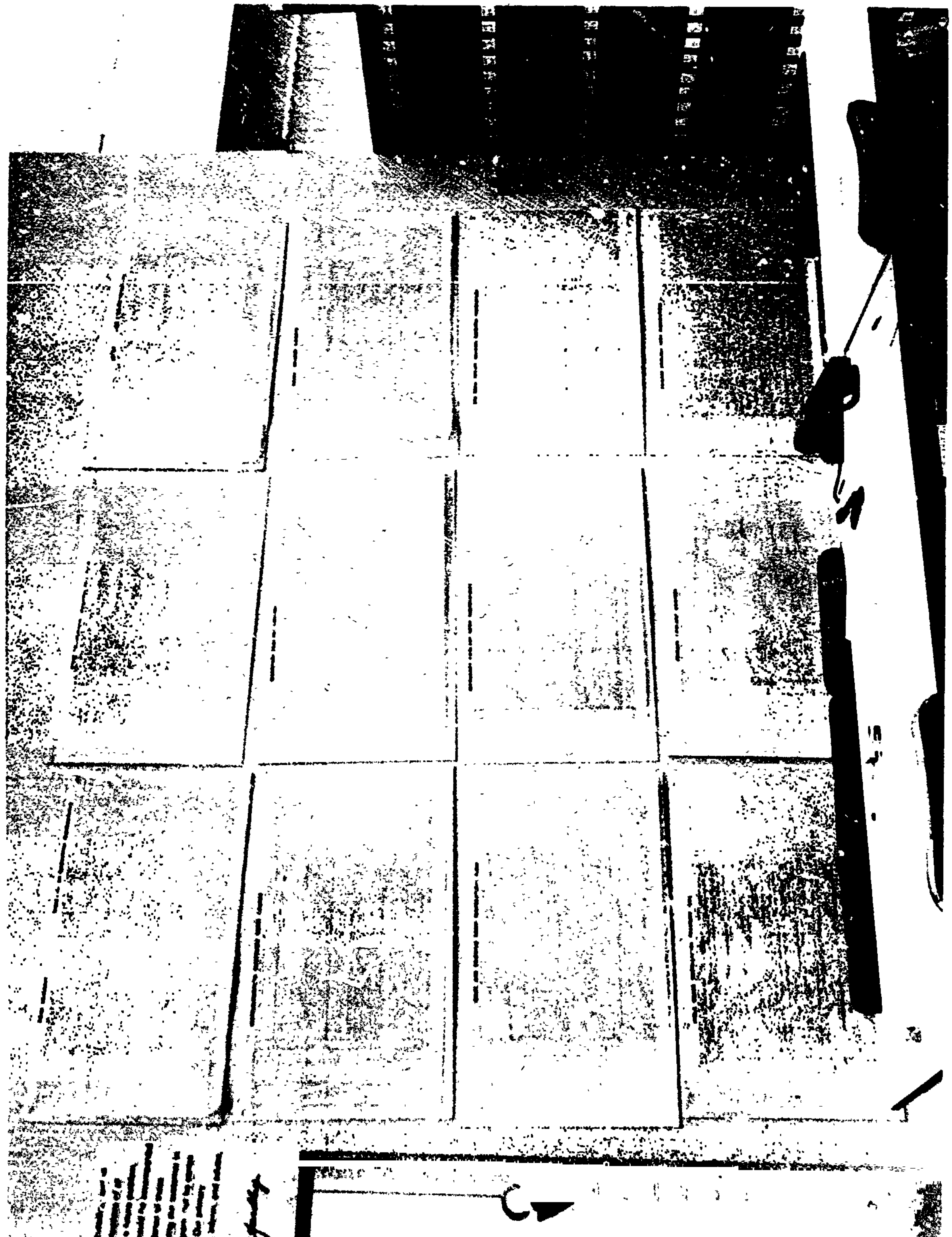


FIGURE 7-3 SYSTEMS TREND CHARTS – COMM CENTER

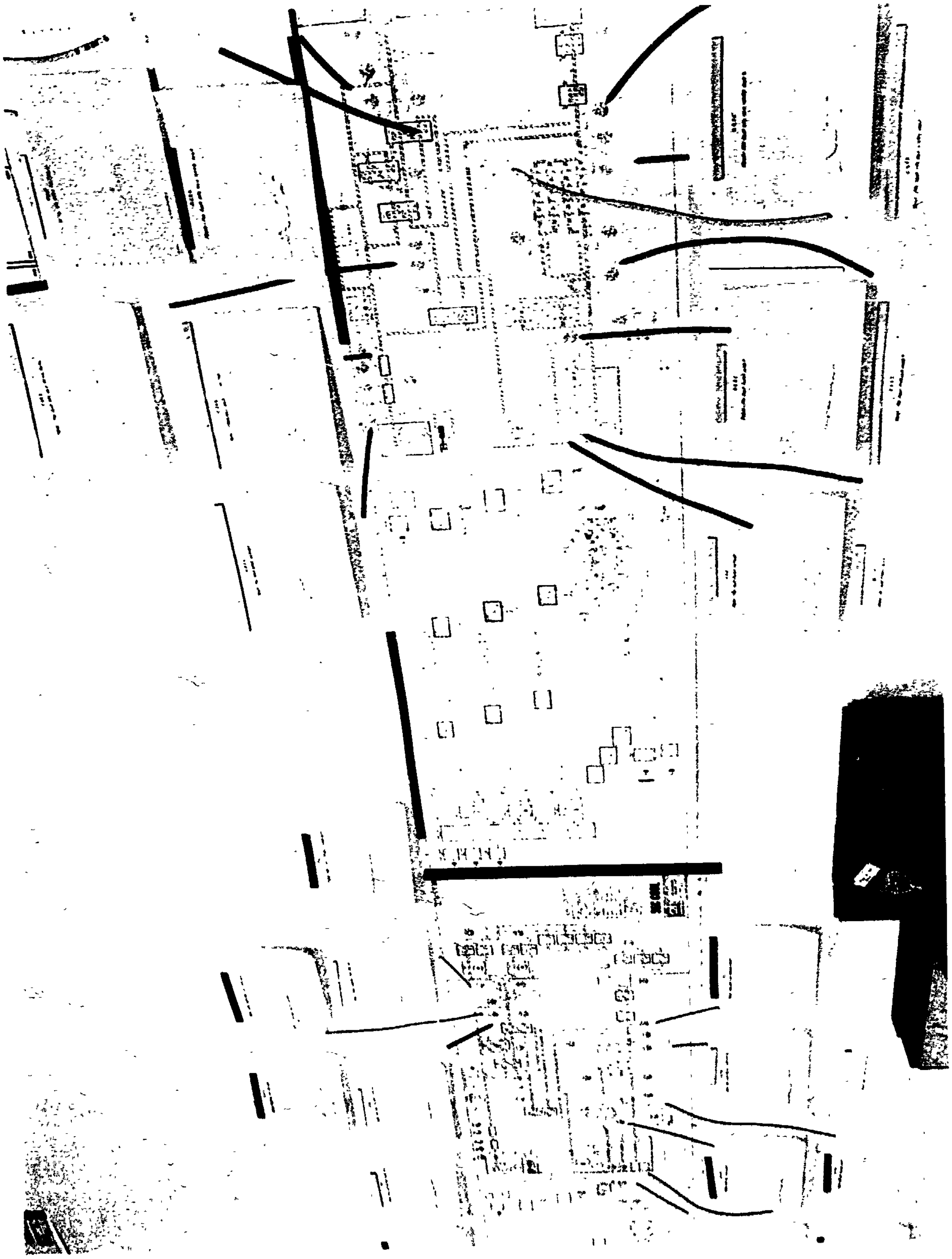


FIGURE 7–4 SYSTEMS SCHEMATICS AND TREND CHARTS – COMM CENTER

- Telephones (4 lines and 2 instruments).
- Video tape recorder and playback.
- Conference table and chairs.
  - Telephone (4 lines with one conference speaker and one instrument).
- Magnafax (2-4/6 minute automatic receive).
- TV monitor (23" with tape playback capability and commercial tuner).
- Clocks (2 - 24-hour and 12-hour).
- 16 MM kinescope projector.

• Conference Room
  - Conference table and chairs.
    - Telephones (4 lines with two conference speakers and 10 instruments).
  - TV monitor (23" with tape playback capability and commercial tuner).
  - 16 MM projector screen.
  - Clocks (2 - 24-hour and 12-hour).
  - World map with orbit overlay.
  - Wall multiplex with Airlock panel layouts.
  - Library containing
    - System descriptions and schematics
    - Crew procedures
    - Malfunction procedures
    - Mission Rules
    - Mission Plans

Voice Communications - Two-way voice communication between MDAC-E and the MSFC HOSC was provided by telephone. Multiple line instruments and speaker phones provided voice communication with other NASA Centers and other Contractors, simulatenously, if required.

GOSS Voice and Flight Director Communications - Loudspeakers in the St. Louis Comm Center allowed MDAC-E and local NASA personnel to monitor the voice communications between the inflight crew and the flight director and his support personnel. This allowed real time cognizance of the crew reports to the ground as well as a real time understanding of the Flight Director activities.

Other Communications - Mission data and NASA action requests were available in the following forms:

- Magnafax was employed to transmit written or diagrammatic information.
- Pictorial information was available by close-out photographs, TV tapes, or Kinescope film.
- Greenwich Mean Time (GMT) clocks were available in the facility, synchronized with the clocks at MSFC HOSC.

Staff - The staff of the Airlock Comm Center was under the direction of the Operations and Evaluation Coordination Group. The duties performed by the Comm Center Staff were as follows:

- Provide technical coordination of Action Requests and responses.
- Provide personnel location.
- Provide access control the the Comm Center and voice loudspeakers.
- Operate magnafax.
- Operate tape recorders.
- Maintain data files.
- Provide administrative support for data handling and NASA Mission Action Requests.
- Provide real time charting of Airlock system parameters.

Access Control - Access to the Comm Center was limited to personnel performing Mission Operations support. Special badges were utilized to control access.

Personnel Locator - MDAC-E maintained a personnel locator system at St. Louis during selected prelaunch operation activities. After 15 January the personnel locator service was maintained full time (24 hrs/day, 7 days/week). Personnel locators were apprised of location status of key personnel and were trained to use telephone networks to locate the individual required for operation support. In order to reduce the time delay in contacting key personnel and to help alleviate the constraints placed on personnel during the mission, the use of Radio Relay Paging System units (beepers) was implemented. Key Airlock personnel were provided with a radio frequency signaling device which provided a "beep" tone signaling the necessity to contact the locator for a message.

7.3.2 Back-Up Flight Hardware (U-2)

The backup Airlock flight article, which by contract was identical to the flight hardware and which had been set up for final checkout tests, was maintained in simulated flight test configuration to provide mission support simulations as needed. Even though the setup did not allow simulation of space vacuum or solar heating, it did allow accurate duplication of system function and interrelation of locations of all equipment in the Airlock/MDA. During the critical SL-2 mission the U-2 was maintained in a powered up, simulated flight mode on a seven day per week, three shift basis. This staffing was relaxed to five days per week, one shift, during the SL-3 and SL-4 missions with provisions to call in required personnel for extended coverage, if required.

The U-2 was supported by the following simulator hardware:

- Solar Array Simulator
- OWS Simulator
- ATM Simulator
- PCM Input Simulator
- Telemetry Ground Station

A procedure was prepared to facilitate accurate simulation of the inflight Airlock systems. This document covered the prelaunch, launch, system activation and deactivation phases of the Skylab Mission. The procedure was based on the following:

- KSC Countdown
- IU Command Sequence
- Skylab Command Procedures Handbook
- Skylab Flight Plan
- Crew Checklists

The Skylab Flight Plan updates, magnafaxed daily from MDAC-E personnel at MSFC, were used to update the simulation procedure. Figure 7-5 shows the Back-Up Flight hardware test setup.

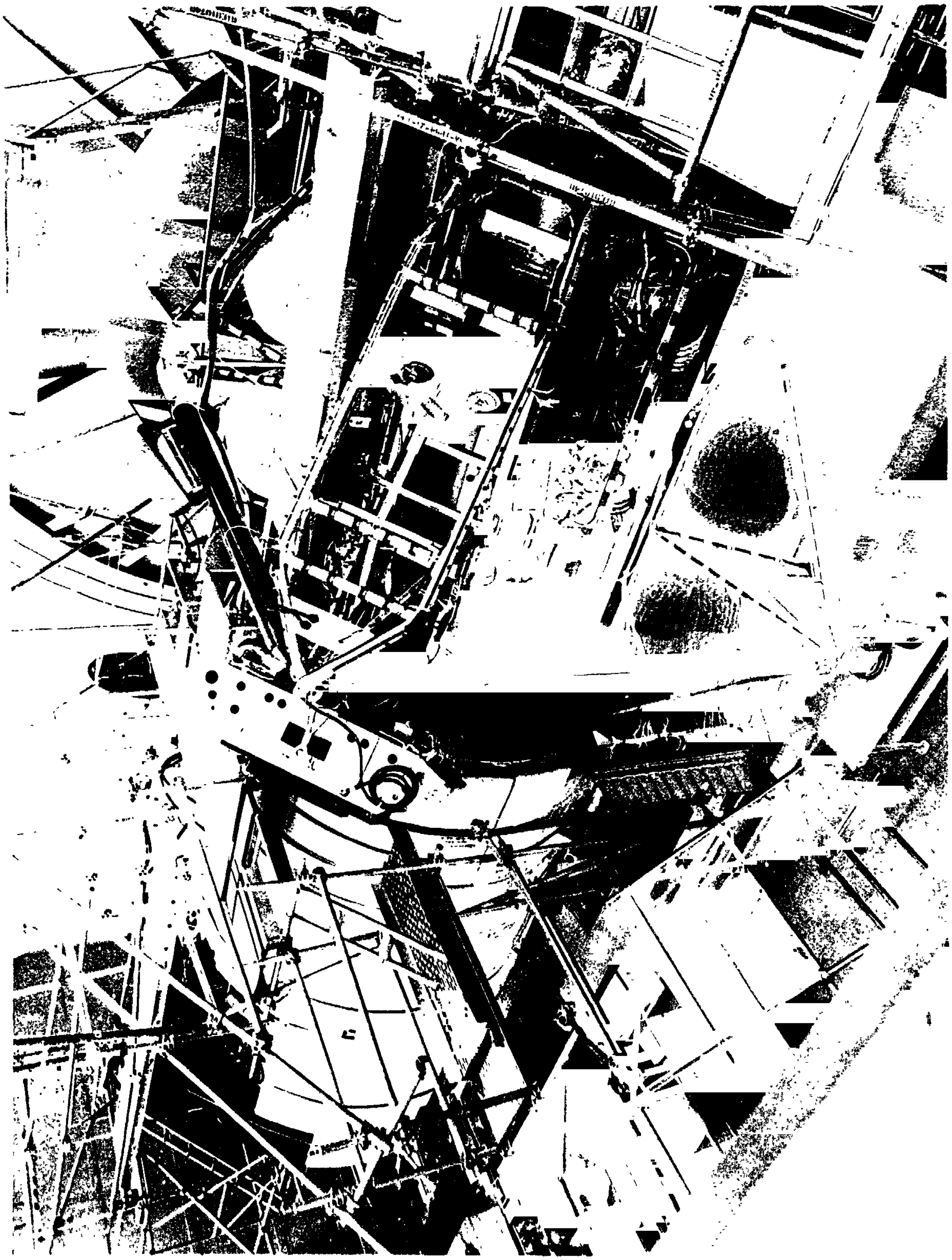


FIGURE 7-5 U-2 BACKUP FLIGHT HARDWARE

7.3.3 I&C Skylab Test Unit/Spacecraft Tracking and Data Network (STU/STDN)

The STU/STDN was a Skylab engineering test and simulation facility designed and developed by MDAC-E for pre-mission and mission support. The facility was used for pre-mission evaluation of performance of on-board Airlock Module Systems. As a mission support tool, it was used to analyze problems encountered during the mission by using simulation to determine the probable cause of the problem and to test possible solutions. In addition, real time telemetry data was received and processed during Skylab passes over St. Louis.

The facility simulated approximately 11,000 electrical interfaces among 164 components within the Skylab systems. A history of commands transmitted to Skylab was maintained in order to allow identification of vehicle configuration throughout the mission timeline and to maintain a current status of the I&C systems and provide accurate duplication of anomalies and quick problem analysis. The facility received the telemetry RF links from Skylab via a tracking antenna, monitored the RF signals for transmission quality, and recorded and processed the data received for evaluation of systems performance. It could also process tapes of Skylab data received at other STDN sites for detailed evaluation of specific system anomalies by MDAC-E/NASA engineering. The facility data processing was geared to provide the data required for expedient system/equipment performance determination, in the minimum number of pages without sacrificing quality of the data. This was done by printing related data on the same tabulation, by providing system schematics with applicable telemetry measurements and by flagging measurements which were outside predetermined limits.

Simulation Facility Equipment

The principal equipment items of the STU/STDN facility were:

- AM/OWS/ATM/MDA I&C Electronic Simulator.
- CSM I&C Electronic Simulator.
- Data Acquisition System (DAS).
- Command Control Console (CCC)/Data Processor.
- Manned Space Flight Telemetry Decommutation Equipment (MSFTP-I and MSFTP-III).
- Up Data Buffer (UDB) and UHF FM transmitter.
- S-Band ground station equipment.
- VHF quad-helix auto-tracking antenna.
- Special station support equipment (video processing and facility test equipment).

A block diagram of the facility is shown in Figure 7-6. Figure 7-7 is a block diagram of the AM/OWS/ATM/MDA Simulator. Figures 7-8 through 7-10 illustrate the equipment configuration.

AM/OWS/ATM/MDA and CSM Simulations

The AM/OWS/ATM/MDA and CSM Simulators simulated the electrical interfaces of the Skylab audio, caution and warning, time reference, AM digital command, AM/OWS telemetry, ATM command, ATM telemetry, video and power systems. Hardline RF interfaces were provided between the command transmitters and receivers, the PCM telemetry transmitters and data acquisition receivers, and the CSM simulator and the S-Band ground station.

The audio and video systems of the AM/OWS/ATM/MDA simulator were interfaced with the CSM simulator where the signals from these were processed and transmitted downlink, via hardline, to the VHF and S-band ground station. The CSM simulator transmitted and received VHF AM on carrier frequencies of 259.7 MHz and 296.8 MHz. S-band PM uplink reception was at 2106.4 MHz and downlink transmission at 2287.5 MHz. A separate transmitter within the CSM simulator tuned to 2272.5 MHz was used to transmit video to the S-band ground station. Simulated ATM TV or crew TV was provided for either real time TV or tape recorded dumps.

At the S-band ground station, the CSM downlink audio was demodulated in the Signal Data Demodulator System (SDDS) and fed to a splitter/interleaver. The splitter then distributed the audio to speakers and recorders as required. Uplink voice from a microphone (or from the AM/OWS/ATM/MDA simulator) was used to frequency modulate a subcarrier which in turn phase modulated the RF carrier to the CSM simulator.

After the ground station demodulated the downlinked video signal, the video was processed and recorded on a VTR. A color converter and a second VTR simulated the JSC facility for processing the video for the commercial networks. Several TV displays and commercial TV test equipment provided for evaluation of the video signals.

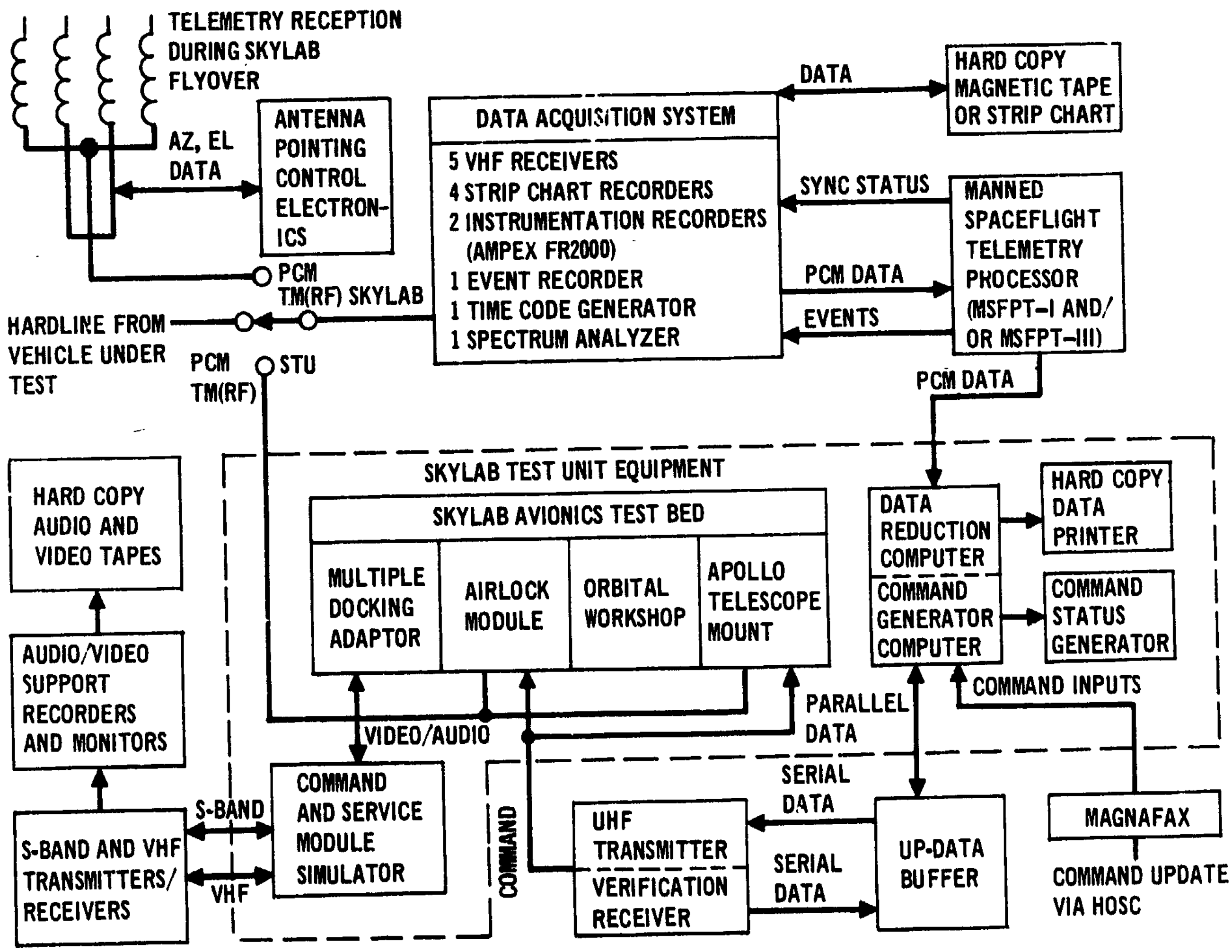


FIGURE 7-6 SKYLAB STU/STDN BLOCK DIAGRAM

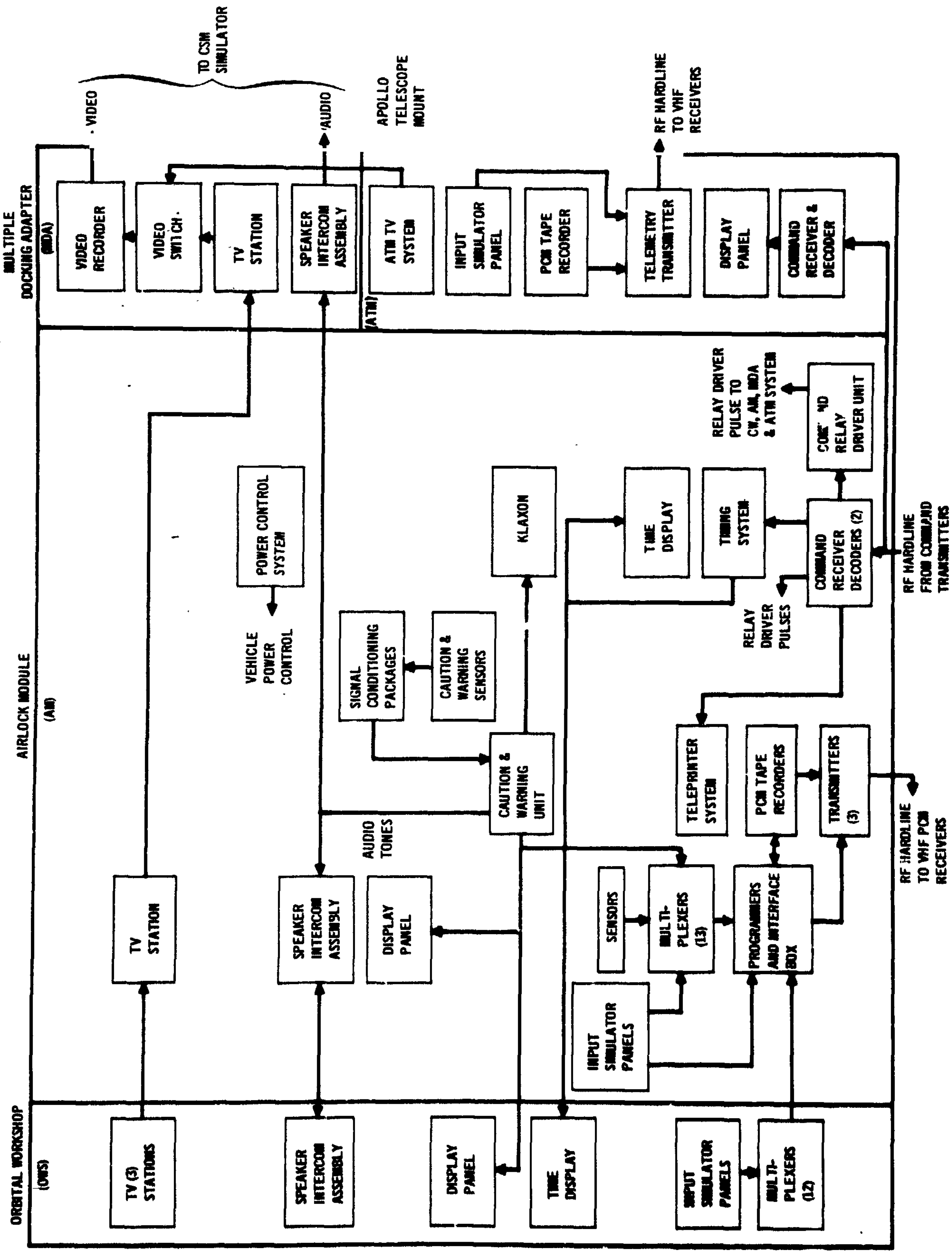


FIGURE 7-7 AM/OWS/ATM/MDA SIMULATOR BLOCK DIAGRAM

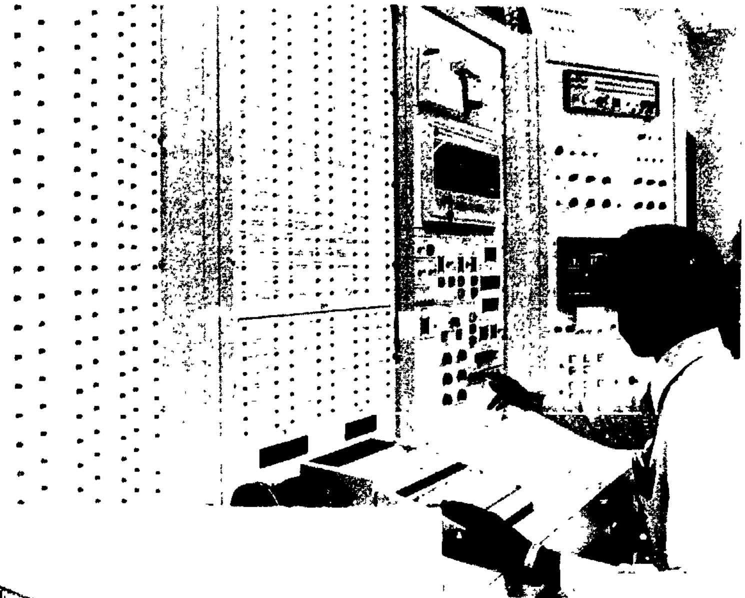


FIGURE 7–8
STU/STDN COMMAND
CONTROL CONSOLE

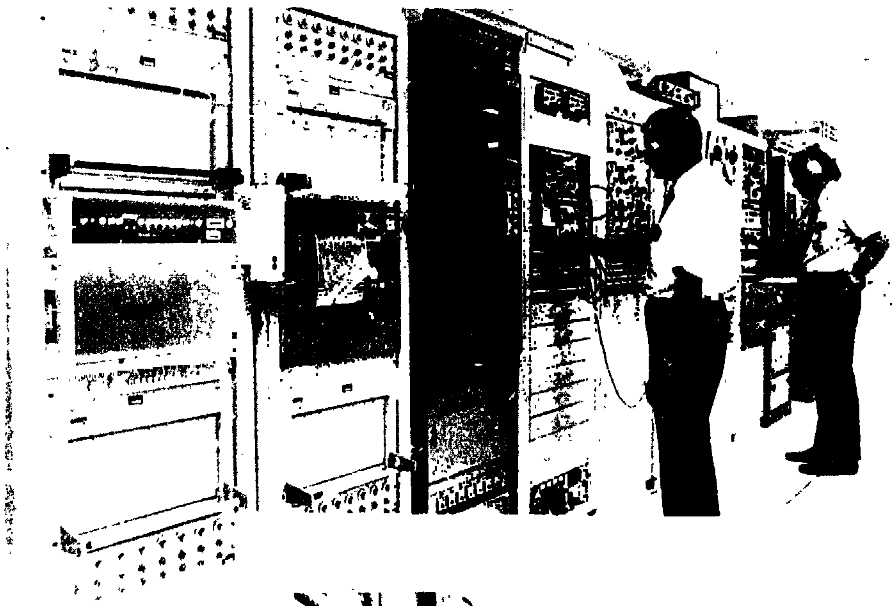


FIGURE 7–9
STU/STDN DATA
ACQUISITION SYSTEM

FIGURE 7–10
TV EQUIPMENT AND
S-BAND GROUND
STATION

Data Acquisition System (DAS)

The DAS had the capability to receive telemetry transmission from the STU AM/OWS/ATM/MDA simulator or downlink transmission from the Skylab via the quad-helix tracking antenna whenever Skylab was in line-of-sight. The telemetry data was received by the five receivers, three tuned to the AM frequencies and two tuned to the ATM frequencies. Output of the receivers was recorded on magnetic tape and also coupled to the MSFTP-I (-III) for decommutation. After decommutation by the MSFTP, the telemetry data was recorded on the analog or event recorders and also transferred to the data processor where it was processed by computer and a hard copy was printed by a hi-speed printer.

Command Control Console/Data Processor

A unique item in the I&C STU facility was the Command Control Console (CCC)/ Data Processor. The data processing function of this equipment will be discussed later. The CCC consisted of an equipment console with a control panel, two display panels, a general purpose digital mini-computer, keyboard and printer, an input/ output (I/O) system and a power distribution system. The primary function of the CCC was to generate, store, display and transmit commands to the STU via the Up Data Buffer (UDB). Airlock commands were displayed on the CCC display panels and both AM and ATM commands were printed out when transmitted. The AM command status lights were only updated after verification of the transmitted message via the UDB. An overall CCC system block diagram is shown in Figure 7-11. The central point of control was the digital computer with communication to or from the I/O system. The operator maintained overall system operation control from the control panel for command generation, storage and transmission. A high speed paper tape system was included for program loading and dump or preparation of object tapes.

During the Skylab mission, a history of active commands transmitted to Skylab by STDN was received via magnafax, reviewed by the operator, and entered into the CCC. There the commands were processed and shipped to the UDB where they were reconstructed into a form suitable for modulating the UHF FM transmitter. The UHF FM transmitter RF output was hardline coupled through attenuators to the AM and ATM command receivers. The RF output was also coupled to a verification receiver which demodulated the RF signal into component audio signals. These audio signals were returned to the CCC after being processed by the UDB. The CCC compared the

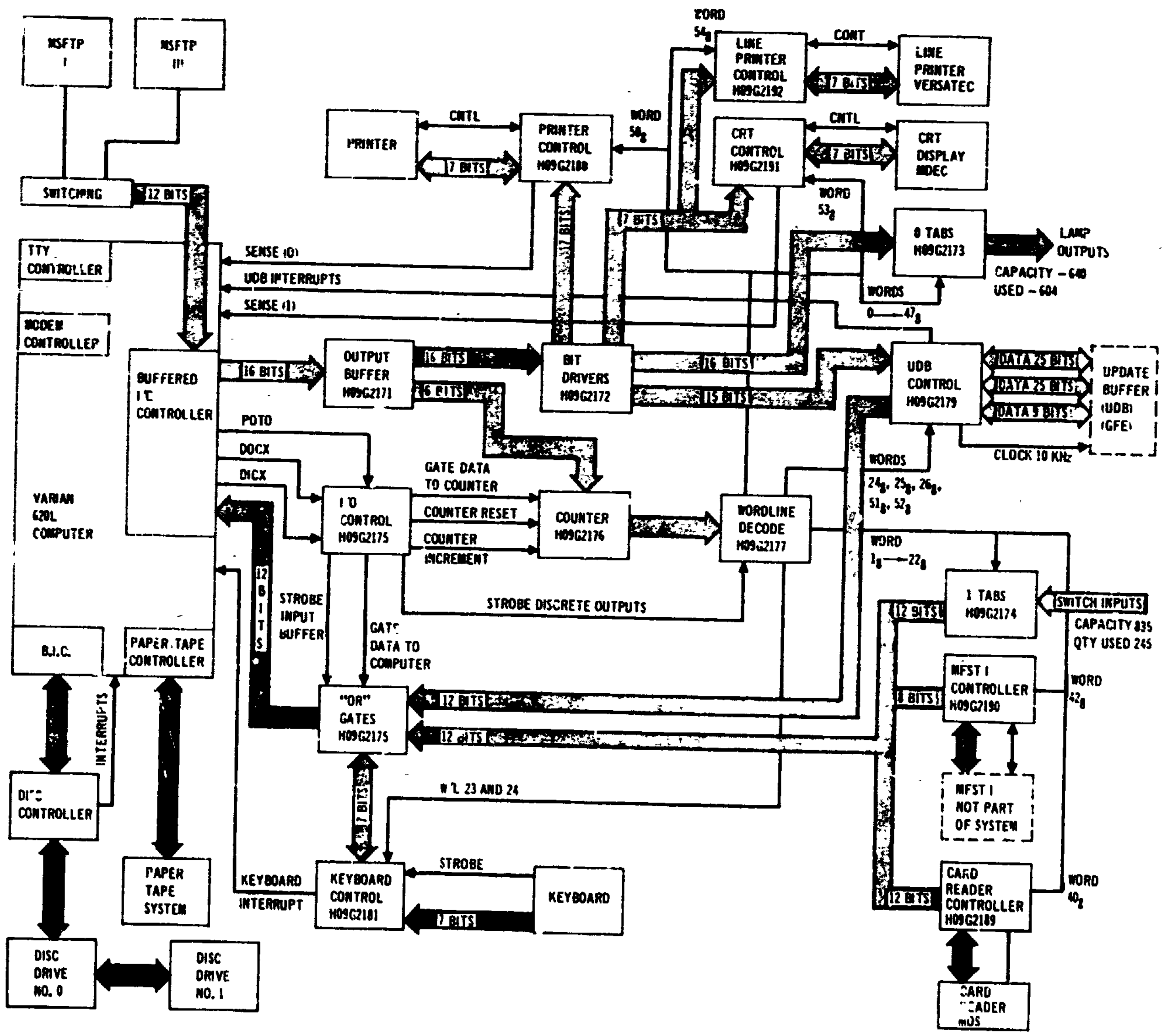


FIGURE 7-11 COMMAND CONTROL CONSOLE INPUT/OUTPUT BLOCK DIAGRAM

received signals with the transmitted message and, if valid, illuminated the appropriate command status indicator.

The CCC performed three additional tasks. Task A provided for computing the present configuration of the converters, programmers, electronics, the three recorders, and the three AM transmitters using instrument control switch settings, commands sent by the CCC, and malfunctions inserted by the operator. The status and malfunction conditions were displayed to the operator on the status CRT. Task B provided for computing required reconfiguration commands using command reconfiguration switch settings. The commands required to reconfigure the system from an existing status to the desired reconfiguration status were calculated and displayed to the operator on the status CRT. Task C involved the performance of a failure analysis between an existing status and the failure symptom status inserted by the operator. All possible failures were displayed to the operator on the status CRT.

Real Time Tracking and Data Reduction

After acquiring the VHF quad-helix auto tracking antenna, a capability for telemetry data reduction and real time data tabulations was incorporated in the STU/I&C facility. Use was made of the inherent data processing capability in the CCC. A unit was designed to interface the PCM decommutator with the CCC computer. This interface consisted of fifteen lines:

- Twelve parallel data lines.
- One decommutator synchronization status line.
- One line to determine start of a new data frame.
- One line to identify the transfer of a new data word (word rate pulses).

By transferring all data words to the computer and by allowing the computer to count the word-rate pulses, the computer was able to select the desired data word(s) and thus eliminated unique patching or programming of the PCM decommutator. To insure credibility of transferred data, the computer monitored for continuous decommutator synchronization and the proper number of word rate pulses between start of frames. The computer accepted and stored a frame of data only if the above two conditions were correct. Provision was made to override this function and accept noisy data if desired.

A punched card reader and high speed printer were included in the CCC system. Instructions to the computer were input by two card decks.

Deck "A" set the PCM format variables, identified each parameter, established the engineering unit value and decimal point location, specified the parameter locations in both the real time frame and delay time subframe, and defined equation coefficients to equate data bit counts to engineering units. Deck "B" identified each parameter, provided a parameter title, and specified the parameter range or tolerance.

After loading, Deck "A" was maintained in computer memory. Upon receipt of signals from the decommutator, the computer selected and stored the desired PCM data words on disc storage unit. Following completion of signal transfer, Deck "B" was entered and, by the order of card entry, established the arrangement of the parameter printout. The computer sought the desired parameters from the disc, compared them for out-of-tolerance conditions, manipulated the count value to engineering unit values, and transferred the information to the hi-speed printer for printout. The number of displayed data tabulations was normally limited by allowing each parameter to be evaluated only once per frame. Other editing techniques allowed further minimization of the quantity of data generated (e.g. printing one out of ten stored data frames). Detailed evaluation of parameters sampled more than once in a data frame could be performed by appropriately modifying the card decks. Figure 7-12 illustrates the Skylab Data Presentation Techniques along with the approximate time usage of the STU/STDN facility during tracking and data reduction periods.

7.3.4 AM Environmental Control System/Thermal Control System Skylab Test Unit (ECS/TCS STU)

Background and Description - The ECS/TCS STU system was adapted from the test hardware assembled to conduct the ECS/TCS Endurance Test identified as the ET-1 test (TR 061-068.35). This test was an eight month real-time test following the Skylab mission time-line of 6554 hours, including three active phases and two orbital storage phases. The test hardware included more than 90 Airlock flight configuration components assembled into a functional system. This included the associated electrical, communication, and instrumentation components as well as the ECS/TCS components necessary to simulate real time operation under the environmental conditions expected on the Skylab Mission. This rather extensive representation of ECS/TCS system

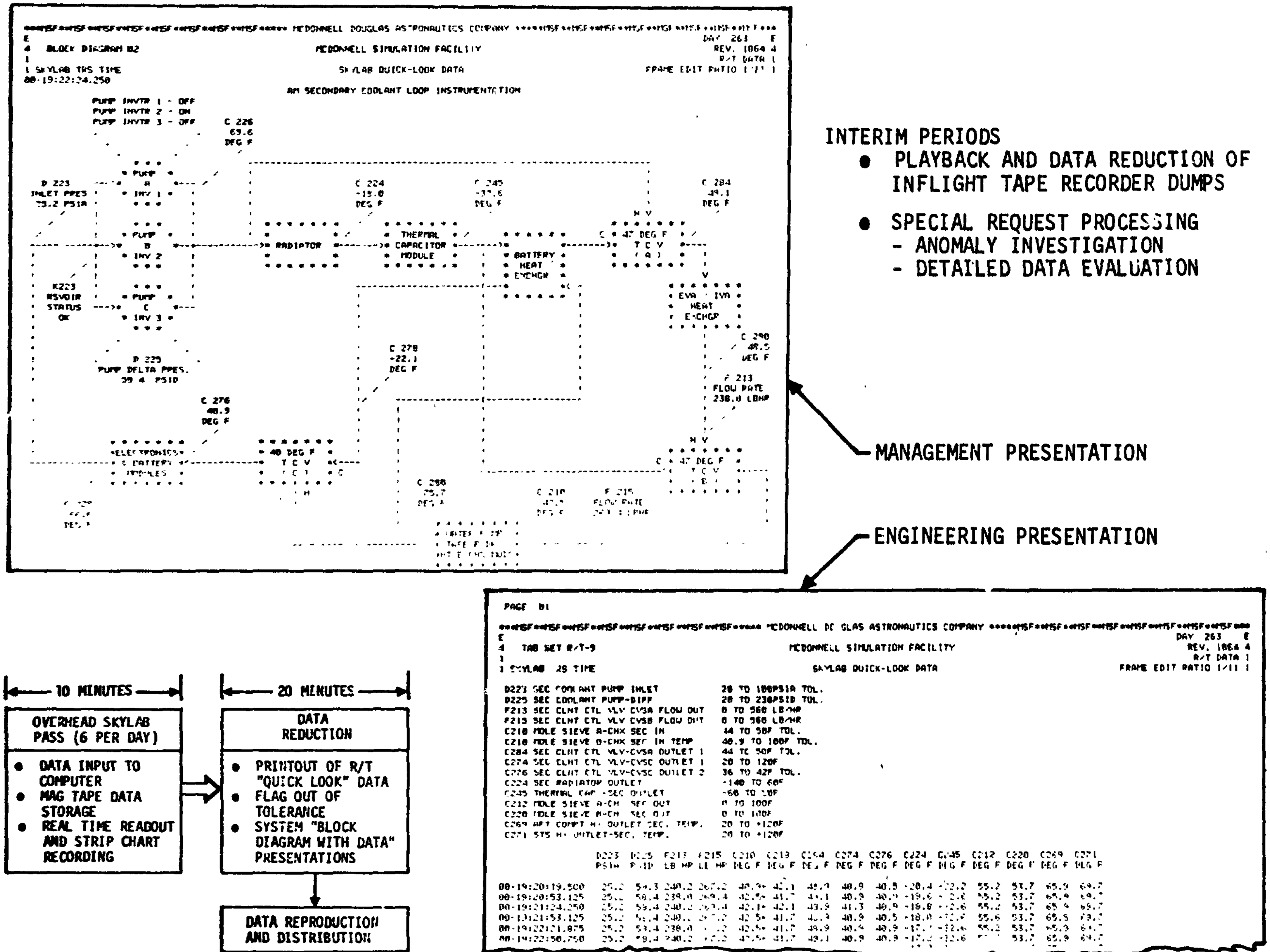


FIGURE 7–12 DATA PRESENTATION TECHNIQUES

was: 1) updated and expanded to integrate relatively recent design changes; 2) retrofitted with spare equipment where appropriate; and 3) serviced and checked out as a mission support/flight anomaly test bed.

Figure 7-13 is an overview that depicts the ECS/TCS ground test simulation capabilities. Significant additions to the ET-1 test bed were as follows:

- Added suit/battery cooling module.
- Added molecular sieve and associated upstream and downstream components and ducting.
- Added EVA/IVA water loop.
- Upgraded ATM C&D/EREP cooling system to include MDA equipment heat load simulation.
- Added thermal capacitor to coolant loop.

Location - The ECS/TCS STU was located in the McDonnell Douglas Space Simulation Laboratories in St. Louis. Figures 7-14 and 7-15 depict the ECS/TCS set-up which utilized the 18-ft. diameter chamber as the cabin simulator and a smaller five-foot diameter chamber to simulate the external environment.

Functional Capability - As stated above, the ET-1 test was modified to provide a more complete simulation of the coolant and water loops and the capability to operate a complete molecular sieve system. The ECS/TCS STU test configuration schematic is given in Figure 7-16.

Auxiliary STU Test Arrangements - Additional ground simulation capability was provided by retaining several of the smaller AM component development and/or qualification test setups utilized early in the AM test program. These auxiliary test set-ups were as follows:

- SUS Water loop - including astronaut life support assembly (used for double-umbilical performance test).
- Condensate system - water separator plate wetting and water dump to OWS holding tank.
- Condensate system overboard dump.
- CO_2 detector performance. (Used to evaluate U1 detector filters)
- Life Support Assembly (LSU)
- Internal hatch - performance/function/leakage.
- Power conditioning group simulated mission (battery cycle test).

SYSTEM	PARAMETER/CAPABILITY	RANGE/LIMITS
CABIN SIMULATOR (INSIDE PRESSURIZED CABIN)	PRESSURE INDEPENDENT PUMPING GAS HEATING HUMIDITY CARBON DIOXIDE INJECTION SIMULATED CABIN LEAKAGE MOL SIEVE	AMBIENT TO $<10^{-5}$ PSIA AMBIENT TO 0.5 PSIA TO 3,000 BTU/HR 0-95% RH 0-100% 0-25 CFM
EXTERNAL ENVIRONMENT SIMULATOR (INSIDE THERMAL CURTAIN)	WALL TEMPERATURE-CONSTANT WALL TEMPERATURE-CYCLING PRESSURE	20°F TO 130°F AS REQUIRED AMBIENT TO 10^{-5} PSIA
COOLANT SYSTEM	SIMULATE FLIGHT SYSTEM ADD HEAT AT PUMP INLET HEAT REMOVAL RADIATOR OUTLET TEMP. (CONSTANT) RADIATOR OUTLET TEMP. (CYCLE) RADIATOR ΔP SYSTEM ΔP RADIATOR BYPASS VALVE THERMAL CAPACITOR SAMPLING CAPABILITY	2 PUMP OPERATION TO 5,000 BTU/HR TO 10,000 BTU/HR AMBIENT TO -10°F AS REQUIRED ADJUSTABLE ADJUSTABLE REMOTE SWITCHING
WATER SYSTEM	PRESENT ATM SYSTEM SIMULATE FLIGHT LCG SYSTEM ADD HEAT TO PUMP INLET - ATM HEAT LOAD SIMULATION LCG HEAT REMOVAL SYSTEM ΔP - ATM SAMPLING CAPABILITY - ATM LIQUID-GAS SEPARATOR - LCG	 2,500 BTU/HR +4,000 TO -1,000 BTU/HR TO COOLANT SYSTEM ADJUSTABLE
CABIN GAS CIRCULATION SYSTEM	SUIT COMPRESSOR POWER SUIT COMPRESSOR ΔP SUIT COMPRESSOR ΔP PLV FAN POWER PLV FAN ΔP GAS CIRCULATION VALVE CABIN HEAT EXCHANGER CONDENSING HEAT EXCHANGER GAS SELECTOR VALVE	0-30 VDC CONSTANT VARIABLE 0-30 VDC OPEN/CLOSE AUTO-CYCLE
CABIN GAS CONTROL SYSTEM	120 PSI O_2 REGULATOR 150 PSI N_2 REGULATOR 5 PSI WATER BOTTLE REGULATOR CABIN PRESSURE REGULATOR O_2/N_2 CONTROLLER CABIN PRESSURE SWITCH N_2 SELECTOR VALVE O_2 HIGH PRESSURE SUPPLY N_2 HIGH PRESSURE SUPPLY REGULATE GAS INLET TEMPERATURE O_2 SOLENOID VALVE AND ORIFICE	REMOTE SWITCHING REMOTE SWITCHING REMOTE SWITCHING REMOTE SWITCHING REMOTE SWITCHING 0-3,000 PSI 0-3,000 PSI AMBIENT TO -10°F
CONDENSATE SYSTEM	COLLECT AND DISCHARGE CONDENSATE SAMPLE CONDENSATE	
INSTRUMENTATION	FLIGHT PO_2 SENSOR FLIGHT CO_2 SENSOR FLIGHT PRESSURE LOSS DETECTOR FLIGHT HUMIDITY SENSOR FLIGHT UV FIRE DETECTOR FLIGHT COOLANT FLOWMETER FLIGHT TEMPERATURE SENSORS FLIGHT GAS FLOWMETER FLIGHT PRESSURE TRANSDUCERS	

FIGURE 7-13 AIRLOCK ECS/TCS STU CAPABILITIES

FIGURE 7-14 ECS/TCS STU CABIN ENVIRONMENT CHAMBER

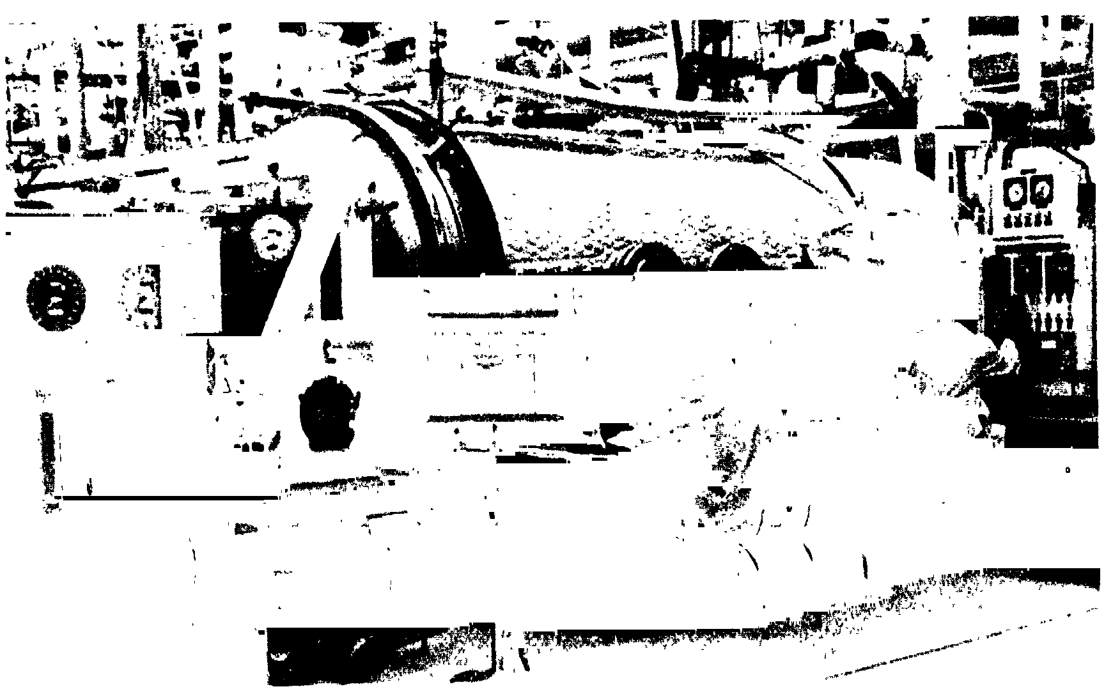


FIGURE 7-15 ECS/TCS STU EXTERNAL ENVIRONMENT CHAMBER SIMULATION SETUP

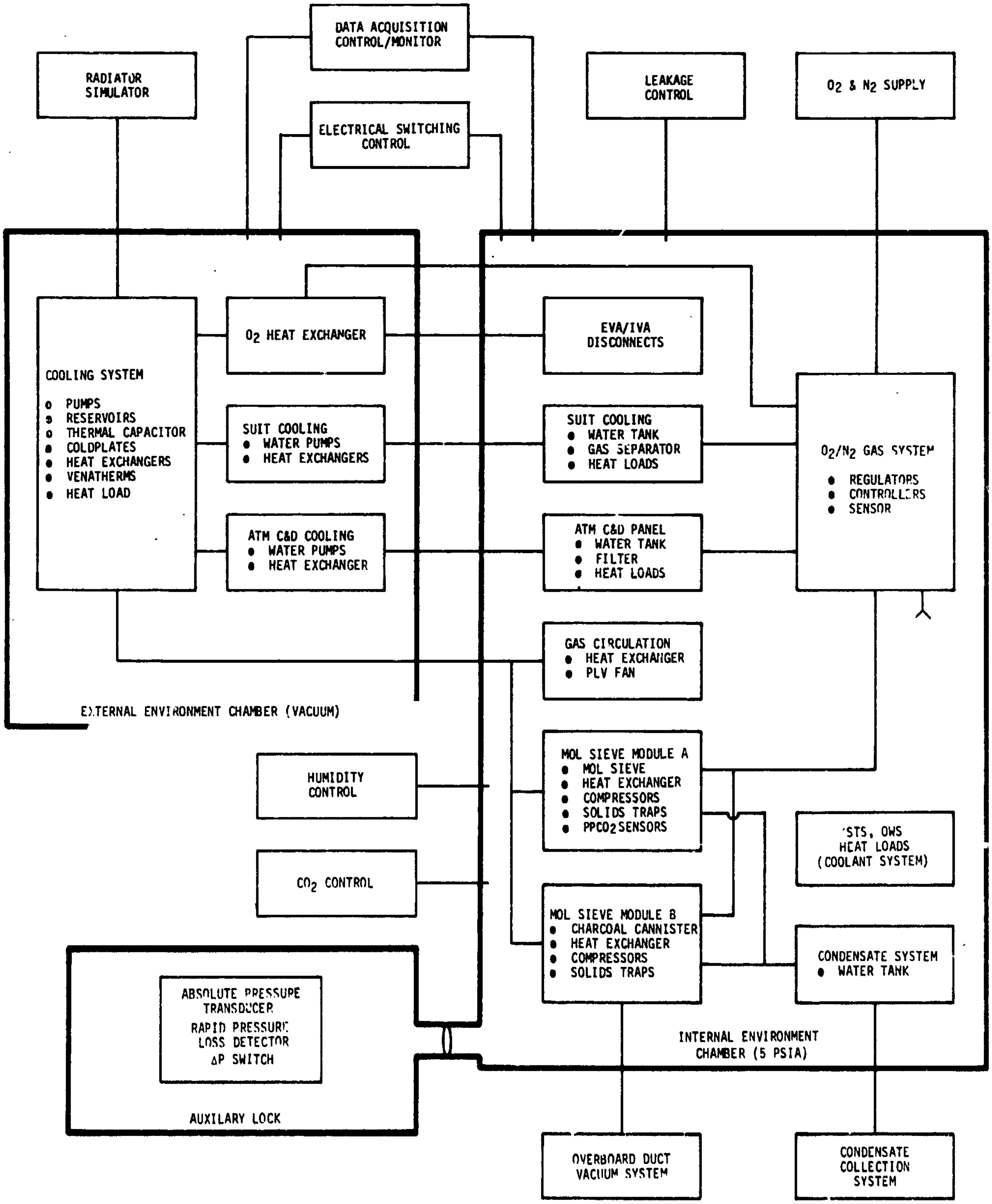


FIGURE 7-16 ECS/TCS STU TEST CONFIGURATION

In addition to basic ECS/TCS STU system and the auxiliary test arrangements mentioned above, the complete MDAC-E laboratories facilities were available as the need arose, and were utilized to support several test activities during the Skylab mission support testing period.

7.4 MISSION SUPPORT ACTIVITY

Support provided by the Airlock Project to MSFC can be considered separately in three specific categories, Pre-Mission, Mission Operations, Mission Evaluation.

7.4.1 Pre-Mission

Mission Operations Design Support (MODS) - This activity consisted of an in-depth functional analysis of Airlock systems. In addition to the inherent system design reliability, redundancy and obvious corrective actions available, the analysis focused on unique procedures which, when performed by the crew and/or ground commands, could result in complete or partial recovery of the failed system or function within a system and enable mission continuance with partial or complete accomplishment of the mission objectives. The results of this analysis were submitted in MDC Report E0321, Airlock Module Systems Malfunction Analysis.

In addition to the malfunction analysis of Airlock systems, this activity provided review of and inputs to the Skylab Launch Mission Rules and Flight Mission Rules.

Mission and Flight Planning - This activity maintained an Airlock Project technical data file of Mission and Flight Planning Documentation and provided a single point for coordination and integration of review comments from selected operations documents.

Operations and Evaluation Planning - In the pre-mission period, MDAC-E provided support to the NASA Mission Evaluation Working Group (MEWG), Operations Support Planning (OSP) meetings, and Mission Support Groups (MSGs). Among the tasks supported were the following:

- Supported the definition of requirements for HOSC displays and facilities.
- Defined documentation required and established on-site (Huntsville) data file.
- Defined mission data requirements and auto scan requirements.
- Attended operations and evaluation planning meetings.

In order to prepare the St. Louis personnel and facilities for Mission Support, the following tasks were performed by Mission Operations personnel in St. Louis.

- Defined training and simulation support requirements.

- Defined Mission Support Hardware Plan (MDC Report E0571, dated 17 March 1972 and revised 20 April 1973).
- Defined Mission Support Software Plan (MDC Report E0723 dated 8 December 1972).
- Defined Mission Operations Support Plan, dated 21 July 1972 and revised 12 February 1973.
- Reviewed for completeness and consistency.
  - Airlock mission auto scan requirements
  - Airlock mission data requirements
  - Airlock mission data reduction plans

Mission Simulations

MDAC-E personnel participated in prelaunch NASA mission simulations in a mission support role. These simulations helped to verify the Mission Support procedures and reports and provided training for MDAC and NASA personnel.

Launch Operations Support - The Airlock Project provided support to KSC in the Pre-Launch period for the following tasks.

- Consultation support for investigation of anomalies occurring in checkout at KSC. Teams of engineers were sent to KSC as required to support NASA and MDAC groups on site.
- Consultation support for equipment stowage in the Airlock.
- Monitored failure reports. Supported "make play" changes to Airlock designed equipment.
- Monitored Test Conductor voice loops.

7.4.2 Mission Operations Support

MDAC-E performed combined tasks of evaluating Airlock systems and providing technical support to MSFC for flight operations as outlined below.

- Analyzed Airlock system performance to establish system status and trends.
- Provided technical consultation support to NASA Mission Support Group leaders and program managers.
- Assisted in resolution of Airlock system anomalies.
- Provided inputs to NASA reports.

- Provided special support teams from St. Louis to MSFC (i.e. real time support for launch and activation) for limited periods as necessary.
- Supported studies and hardware simulations as requested by MSG's and MSFC Airlock Project Office.

Vendors of major equipment items under Contract to MDAC-E provided support to the Airlock for the following:

- Maintained drawings, test procedures, test results, and design analysis.
- Maintained test equipment and test fixtures.
- Provided information on operation, maintenance evaluation, and repair.

The vendors listed in Figure 7-17 supported MDAC-E for Mission Operations through 31 December 1973 with the exception noted.

<u>On-Site MSFC Operations Support</u> - MDAC-E personnel on-site at MSFC provided technical support to the MSG's responsible for Airlock systems. It was the general duty of on-site personnel to assist in performing systems assessment activities and react to time critical problems in coordination with the group engineer, in St. Louis, responsible for the Airlock system. MDAC-E support personnel at MSFC performed the following functions:

- Coordinated the evaluation of mission changes for Airlock system compatibility.
- Performed systems assessment and assisted in resolution of anomalies during orbital operations.
- Provided system status summary and flight planning information to MDAC-E St. Louis personnel.
- Performed coordination between MSG's, MSFC Laboratories and other contractors.
- Supported the daily and weekly mission reports.
- Collected and transmitted data tapes and plots to the MDAC-E users.
- Coordinated MDAC-E requests for data and data reduction with the MSFC Computation Lab.

The on-site support staff worked directly with the MSG leader, but maintained close contact with the Group Engineer, in St. Louis, responsible for the Airlock system which they were supporting. Daily reports and telephone conferences covered the following areas:

VENDOR	EQUIPMENT SUPPORTED
AIRESEARCH	WATER SELECTOR VALVE COOLANT PUMPS COOLANT PUMP MOTORS MOLECULAR SIEVE FANS COOLANT RESERVOIRS O_2 HEAT EXCHANGER VERNATHERM CONTROL VALVES SOLENOID SELECTOR VALVES CHECK VALVE, MOLECULAR SIEVE FAN OUTLET SOLID TRAPS SHUTOFF VALVES GROUND COOLING HEAT EXCHANGERS REGENERATIVE HEAT EXCHANGERS WATER STORAGE TANKS CABIN PRESSURE RELIEF VALVES CONDENSING HEAT EXCHANGERS WATER SEPARATOR PLATES CABIN HEAT EXCHANGERS WATER CHECK VALVES MANUAL INFLATOR MOLECULAR SIEVE
CARLETON CONTROLS	O_2 REGULATOR N_2 REGULATOR CABIN PRESSURE REGULATOR H_2O TANK PRESSURE REGULATOR MANUAL VACUUM ISOLATION VALVE O_2/N_2 LATCHING SOLENOID VALVE O_2/N_2 FILL VALVES
EAGLE PICHER	BATTERIES
EDGERTON GERMESHAUSEN & GRIER (EG&G)	TRACKING LIGHTS
ELECTRO MECHANICAL RESEARCH (EMR)	TELEMETRY (PCM)

VENDOR	EQUIPMENT SUPPORTED
FAIRCHILD	EXTENDIBLE BOOM
GULTON ENGINEERED MAGNETICS DIVISION	BATTERY CHARGERS VOLTAGE REGULATORS COOLANT PUMP POWER SUPPLIES SUIT COMPRESSOR POWER SUPPLIES
HONEYWELL	FIRE DETECTOR
K-WEST	GAS FLOWMETER O_2/N_2 CONTROLLER COOLANT LOOP AUTOMATIC SWITCHOVER CONTROL
MOTOROLA	DIGITAL COMMAND SYSTEM
PYRODYNE	47° TEMP CONTROL VALVE
RADIO CORPORATION OF AMERICA	RTTA (VHF RANGING EQUIPMENT)
RCA (THROUGH 30 JUNE 1973)	DATA RECORDER
SPECTROLAB	SOLAR ARRAY SIMULATOR
UNITED SHOE MACHINERY (USM)	DEPLOYMENT ASSEMBLY MOTOR/REEL ASSEMBLY
WILOROCO	CURRENT SENSOR
MCDONNELL DOUGLAS ELECTRONICS COMPANY (MDEC)	DC-DC CONVERTER CAUTION AND WARNING UNIT COMMAND RELAY DRIVER UNIT AUDIO AMPLIFIER (HIGH LEVEL) INTERFACE ELECTRONIC UNIT ELECTRONIC TIMER TIME CORRELATION BUFFER DIGITAL CLOCK DIGITAL DISPLAY UNIT

FIGURE 7-17 VENDORS SUPPORTING MDAC-E MISSION OPERATIONS

- Status of systems.
- Anomaly tracking.
- Action item inputs and outputs.
- Daily report inputs.

The on-site MSFC facilities used were at the option of the MSFC organization being supported. The normal working areas were:

- HOSC
- Astronautics or Astrionics Laboratory
- MDAC-E (Huntsville) office area

MDAC-E support activity levels, both on-site and in St. Louis, varied depending on the time of mission and the status of Airlock Module Systems, Figure 7-18.

	MISSION PHASE		
	PRE-MISSION	MISSION	POST MISSION
ST. LOUIS			
TECHNICAL SYSTEM SUPPORT	5-DAY, 40 HR/WK (1)	5-DAY, 40 HR/WK (2)	5-DAY, 40 HR/WK
PERSONNEL LOCATOR	7-DAY, 168 HR/WK	7-DAY, 168 HR/WK	
MISSION SUPPORT COORDINATOR	5-DAY, 40 HR/WK	7-DAY, 168 HR/WK	5-DAY, 40 HR/WK
MSFC ON-SITE			
TECHNICAL SYSTEM SUPPORT	5-DAY, 40 HR/WK	7-DAY, 168 HR/WK (3)	5-DAY, 40 HR/WK
DATA MANAGEMENT AND PERSONNEL SUPPORT	5-DAY, 40 HR/WK	7-DAY 168 HR/WK	5-DAY, 40 HR/WK

(1) ON CALL FOR SUPPORT AFTER NORMAL WORKING HOURS.

(2) TWENTY-FOUR HOUR DAY DURING ACTIVATION AND DEACTIVATION, HIGH ACTIVITY PERIODS, OR MAJOR ANOMALY PERIODS. ALSO ON CALL FOR SUPPORT AFTER NORMAL WORKING HOURS.

(3) SCHEDULED BY EACH SYSTEM MSG TO COMPLEMENT NASA PERSONNEL AND OTHER CONTRACTOR PERSONNEL.

FIGURE 7-18 AIRLOCK PROJECT MISSION OPERATIONS SUPPORT COVERAGE

7.4.3 MDAC-E Evaluation Support

The MSFC Mission Evaluation Working Group (MEWG) was responsible for managing Skylab mission evaluation and for developing the NASA Skylab Mission Evaluation Report (SMER). MDAC-E supported the SMER by providing inputs to MSFC Mission Support Groups (MSG's).

7.4.4 Mission Support Testing

Ground test activity in support of the Skylab mission was conducted on an informal (minimum documentation, reporting and test control) basis for the purpose of obtaining engineering data. Testing was performed with three independent test systems and/or areas. The following provides a definition of the test system and a summary of the test activity performed in support of the Skylab missions SL-1 through SL-4.

7.4.4.1 U-2 Backup Support

Introduction - Mission support testing utilizing the U-2 vehicle started at the time of U-1 delivery to KSC and continued through deactivation of U-1, a total of 16 months. Mission support testing was divided into three major categories:

- The planned utilization of U-2 in a simulated flight mode during U-1 on-orbit operations.
- Performance of special system/component tests.
- Development of hardware installation/change procedures and timelines.

In addition to actual test support of U-1, U-2 provided a source of checked out spares to supply the contingency needs of U-1 during the prelaunch period.

U-2 Flight Simulation - The simulators, procedures, and communications system established for U-2 support allowed near real time simulation of Skylab mission activities. For the simulated flight support mode, the U-2 digital command system controlled the launch sequential functions from lift-off through vehicle activation. The Solar Array Wing Simulator (SAWS) provided a time-varying output to simulate the orbital position of the Skylab. The SAWS output fed the U-2 Power Conditioning Group (PCG's).

In the period launch +5 days through launch +25 days, the AM/MDA was held in a simulated flight, standby mode and the vehicle primarily was powered down. During this 21-day period, to assure the vehicle was operable, systems were powered up periodically to allow them to be reconfigured to reflect the U-1 configuration.

At launch +26 days, U-2 was powered up to support the EVA activity of U-1. After completion of the EVA, the U-2 standby mode (powered down) was resumed.

During deactivation of U-1 simulated support mode was provided. Following completion of Skylab Mission SL-2, the back-up vehicle remained in the Simulated Flight standby mode (powered down) to support U-1 anomaly investigation, as required. Vehicle updating and deferred testing was continued in parallel. The week prior to Skylab 3 launch was used to ready the U-2 vehicle, facilities, GSE, etc., to support the Skylab 3 mission.

The U-2 vehicle was primarily powered down in the simulated flight mode throughout the 59-day Skylab 3 mission. The back-up vehicle was powered up as required, during the manned activation of U-1 and for anomaly resolution support or as required for system maintainability (battery charge, etc.). The staffing was on a one-shift (eight hours) per day, five days per week basis.

After the completion of Skylab 3 mission, U-2 was maintained in a powered down simulated flight mode until 14 October 1973 for post mission anomaly resolution.

U-2 support of SL-4 was similar to support of SL-3. U-2 was powered down except for SL-4 manned activation of U-1.

The U-2 vehicle was powered up in support of SL-1/2 a total of 245 hours; in support of SL-3, 195 hours; and in support of SL-4, 91 hours. The following is a summary of U-2 support:

ACTIVITY	MISSION DAYS	CONFIGURATION	SCHEDULED SHIFTS (8 HOURS)
SL-1 LAUNCH	T-1 TO T+4	POWERED UP	3 PER DAY
SL-2 MISSION	T+5 TO T+25	POWERED UP AS REQ'D	3 PER DAY
SL-2 EVA	T+26	POWERED UP	3 PER DAY
SL-2 DEACTIVATION	T+28	POWERED UP	3 PER DAY
BETWEEN SL-2 & 3	N/A	POWERED DOWN	2 PER DAY$^{\Delta}$
SL-3	59 DAYS	POWERED DOWN	1 PER DAY$^{\Delta}$
SL-4	84 DAYS	POWERED DOWN	1 PER DAY$^{\Delta}$

ΔADDITIONAL ACTIVITY AS REQUIRED

Special U-2 Tests Performed in Support of U-1

- The PCM multiplexer noise problem was resolved.
- The cause of noisy caution and warning parameters was isolated and a "fix" recommended.
- The BILCA autotransformer brush problem was resolved.
- The cause of a flow sensor problem was determined and a "fix" recommended.
- An external sequential circuit breaker panel vibration test was completed and a design change verified.
- U-1 close out was verified by procedures used on U-2.
- The TRS/EREP timing interface was verified.
- The DCS electronic timer interface and timing circuit were verified.
- Mole sieve solenoid valve operation was verified at 22 VDC Bus Voltage.
- Water pump differential pressure sensor resistance measurements were made.
- Static measurements made on U-2 verified U-1 safety considerations.

- A fit test was made of the Fire Sensor Control Panel Lamp Test Assembly.
- A MDA minimum acceptable lighting test was performed.
- Functional verification tests were made on the AM circulation/duct fans cable assembly and extension cable.
- A verification test was performed on the O_2N_2 pressurization system orifice flow control.
- Power system status lights were verified.

Development of Hardware Installation/Change Procedures and Timelines

- U-2 was used to verify the alternate CSM pump module installation.
- Using the U-2, a method was devised for inspecting and drying the upper DA trusses.
- A DA pin puller clevis beef-up was fabricated and the installation procedure demonstrated on U-2 DA.
- U-2 used to establish a non-standard technique to shorten time required for changeout of U-1 SUS water storage tanks.
- Tracking flash heads hard mount fittings were fitted on U-2, then a kit, procedures, and pictures were sent to KSC for U-1 application.
- Fit checks of proposed "fixes" for the OWS thermal problem were made on the U-2 FAS. These checks included the U-1 curtain brackets, FAS Adapter/Deployment Boom Assembly, and the U-1 solar array release.
- Coolant System Reservicing Kit hardware and procedures were verified on U-2.

Hardware Removed from U-2 in Direct Support of U-1

- Battery ammeters
- DC/DC converters
- FAS umbilical plate QD's
- RNBM unit
- SUS QD's and jumper hoses
- Coaxial switches
- Interface Electronics Unit (IEU)
- Fire sensor
- Relay panels
- Switch guard
- O_2N_2 valve handles
- PCM tape recorders

7.4.4.2 I&C STU Support

A. Pre-Mission - During the pre-mission period, 1 January 1973 to 15 May 1973, the I&C STU facility was used to support a variety of end-to-end I&C system tests.

It was used to verify compatible performance of the Audio, Command, Telemetry and Television system interfaces; determine accuracy and adequacy of mission rules and procedures; and to evaluate off-nominal operation of Skylab Instrumentation and Control (I&C) systems and ground system operations.

In conjunction with GSFC, tests were conducted to:

- Provide baseline bit error rate vs. total received power data for individual and combined AM and ATM RF links under various conditions.
- Verify the compatibility of the STDN station to receive, decommutate, and process simulated PCM formats for various decommutation sync strategies.
- Investigate the capability of the STDN station to successfully record, playback, and decommutate AM and ATM delayed time data for various STDN configurations.
- Verify the basic compatibility of generated DCS commands and the AM and ATM receiver/decoders and determine message rejection rates.
- Verify the compatibility of the STDN station with the AM I&C systems and the ATM Command and Telemetry systems and determine (a) the threshold level of the AM DCS when uplinking teleprinter messages, and (b) the correct/incorrect load rate of the Memory Load Unit/ Digital Computer.

Comprehensive tests were conducted on the end-to-end components of the television system to demonstrate the simulation facility readiness, to accumulate a set of television system baseline data to support subsequent system evaluation, and to obtain off-nominal and anomalous performance characteristics. The following calibration data was obtained:

- Static and dynamic transfer characteristic of ground station FM demodulator.

- Signal, noise, and harmonic distortion in the audio splitter output as a function of carrier to noise ratio.
- Gain of the TV input station as a function of control potentiometer setting.

Off-nominal and anomalous tests were performed on the video switch and the TV input station.

Tests were also performed which accomplished the following:

- Verified operation of the AM emergency voice and dump voice procedures, provided word intelligibility tapes to NASA for various receiver power levels, obtained data for speech to noise vs. total received power curves, and established voice quality and system frequency response of the STU audio system in the dump voice mode.
- Provided NASA with a special time voice correlation evaluation tape of a dump of an AM tape recorder over an RF link. The AM tape recorder had been previously recorded using STU PCM data and voice annotation of time marks.
- Provided measurements and waveforms for various STU telemetry parameters as requested by MSFC.
- Performed tests to determine end-to-end performance of the EREP Diagnostic Downlink Unit (EDDU) when EREP data was transmitted through the TV link. Determined S-Band carrier to noise threshold for operation of Miller Code Detector, output levels of code from the grounded TV equipment, and feasibility of recording code on the Ampex FR2000 ground tape recorder. Reported the possibility of EREP data causing the Audio Splitter to switch to VTR mode the' by causing a possible loss in air to ground audio.
- Evaluated change in TV system frequency response when a 100-foot cable was used in place of a standard cable between the TV input station and the portable camera (would have allowed for TV during EVA to inspect possible Skylab repair).
- Participated in simulated flight TV anomaly testing. Two possible failure modes as seen at a ground site were telephoned into the STU lab and the TV equipment was made to malfunction in a mode to reproduce the problems.

- Tested possible de-emphasis filtering network for S-Band downlink voice.
- Isolated the unexpected rapid loss of pressure (rapid ΔP) alarms which occured during AM/MDA/CSM interface testing to internal interference in the sensor. The sensor circuitry was modified and the solution verified.
- Isolated a launch pad anomaly in the teleprinter to an Interface Electronics Unit circuit and recommended a design modification for solution.

Mission Support - The major areas of mission support were real time tracking and data reduction for system evaluation and identification of data trends, responding to action request (AR) type items, and performing video tape evaluation.

The type of activities performed in responding to AR's is illustrated by the following items:

- Investigated light weight head set compatibility with the VTR.
- Investigated audio system acoustical feedback problem and verified the compatibility of the anti-feedback network communication assembly with the audio system.
- Duplicated the DOY 213 garbled dump voice problem and isolated the problem to a particular section in the ALC.
- Verified the feasibility of a CSM rescue mission communication umbilical which would have allowed a radial docked CSM to interface with the SWS audio system.
- Supported testing of hand held microphones.
- Conducted a temperature test on the fire sensor at temperatures between 120°F and 160°F.
- Verified that certain switching conditions could cause erroneous increment of day count on digital display unit.
- Verified that probable cause of momentary rapid ΔP alarms on days 250 and 253 was the accidental opening of a circuit breaker and a switch by the crew.
- Duplicated mission problems of paper feed (loose drive roller), light printing (low AM temperature problem), and printing misalignment (improper paper loading) and advised MSFC as to causes and possible solutions.

- Investigated problem on OWS low-level multiplexer including temperature tests on the multiplexers and recommendations of alternate measurements to obtain the desired data.
- Simulated stuck tape recorder fast forward relay and provided quick turn around problem solution cable for launch on SL-4.
- Prepared video tapes for training SL-3 crew to open and inspect AM tape recorders and conducted SL-4 crew training for AM tape recorder and video tape recorder repair.
- Investigated problems involving the video tape recorder (VTR) recording of audio and audio recovery by the Audio Splitter. VTR troubleshooting and repair procedures were prepared.
- Determined the TV system response to video recordings made with the TV coaxial cable unterminated.
- Performed ATM data reduction (per MSFC phone request) to support evaluation of ATM Control Moment Gyro anomaly.

The STDN site video tapes were reviewed subjectively on TV monitor for black and white and color picture quality. The video was examined on a waveform monitor to obtain quantitative measurements of signal to noise ratio, video to sync format, and portable camera temperature and frequency response. Fifty-four tapes were reviewed during the mission.

Accomplishments - The major accomplishments of the STU/STDN facility include:

- Quick turnaround from go-ahead to completion of facility installation and modification (including hardware and software).
- Provision of continuous dynamic system test bed for mission anomaly duplication and problem solution determination and verification.
- Crew training in repair procedures through training films and crew visits.
- Reception and processing of data for the entire mission allowing ready access to system status by cognizant engineers, evaluation of system trends, and a file of Skylab data for possible re-evaluation.

7.4.4.3 ECS/TCS STU Support

The purpose of ECS/TCS STU ground simulation was to permit definition of system behavior under conditions peculiar to the flight or following a single or multiple failure occurrence. Ground testing permitted the projection of the abnormal or failure situation to other conditions under which the system would be required to operate and allowed definitions of recovery procedures.

A total of 62 test conditions were conducted on either the ECS/TCS STU or one of the auxiliary test arrangements in support of the Skylab mission. The following types of tests were performed during the Skylab mission:

TCS Tests

- U-1 cold coolant simulation.
- ATM pump starting transient test.
- 47° Temperature Control Valve, "B" test.
- Coolant Pump shutdown and startup test.
- Altitude test of 2-watt and 10-watt Airlock Transmitters without cooling.
- Coolant Loop simulated leak tests.
- Saddle Valve tests.
- Coolant System reservicing tests.
- Coolant Pumps Power Inverter startup tests.
- Voltage Regulator thermal vacuum test.
- Primary O_2 Heat Exchanger cold gas test.
- ATM Cooling Loop tests
- Stowage test of the 61A830416-1 Servicing Hose Assembly.
- N_2 flow rate through 61A830355-13 and 61A830356-3 Servicing Hose Assemblies.

ECS Tests

- O_2 Regulator test with cold gas.
- Deionizer Filter Assembly, 1B89235-505, high temperature test.
- CO_2 Detector Filter Cartridge performance verification test.
- Mole Sieve Compressor Power Inverter test.
- Mole Sieve Flowmeter test.
- Exploratory test of the High Pressure N_2 Regulator performance characteristics.

EVA/IVA Suit System Tests

- SUS Loop operation using two 60-foot LSU's in series.
- SUS Loop cooling rates with By-Pass/EVA Valve in BY-PASS position.
- LSU pressure test.
- SUS Water Pump temperature test.

A description of the significant tests performed, with the test results obtained are included in this report in the appropriate Airlock system sections. An overall summary of the STU tests can be found in Appendix D.

7.5 CONCLUSIONS AND RECOMMENDATIONS

7.5.1 Summary of Accomplishments

The Mission Support segment of the Airlock Project provided complete and accurate response to all questions and problems posed by the NASA or Skylab hardware during the mission. These responses were internally coordinated to assure accuracy. Prior to and during the flight of Skylab, a period from 6 October 1972 through 14 February 1974, there was a constant and complete response to all queries. The few hardware anomalies which occurred were expeditiously analyzed and support, in the form of inflight workaround recommendations, test analysis, or hardware modification kits, was furnished on time and with complete NASA concurrence.

Routine accomplishments included continuous, three shift, radio augmented locator service to assure the availability of knowledgeable personnel. Data was collected, plotted, and reviewed to detect any trends in evidence. Special data processing was implemented where necessary to further knowledge of the trend or the potential fix. Action requests were internally coordinated to assure complete agreement prior to submittal to NASA. Many of the NASA action requests required response within one-half hour of receipt. Often the request and response were transmitted by telephone with confirming paper transmitted later by Magnafax.

The successful completion of the nine month Skylab mission with its extended manned mission is evidence of successful Airlock mission support, as well as effective system design and verification. It is also worthy of note that the Airlock could have continued to support the mission for an extended, indefinite period; all systems were fully operational at end-of-mission.

7.5.2 Valuable Systems and Procedures

Several philosophies related to Mission Support were sufficiently effective that they are recommended for future orbital flight support programs.

A central clearing point in each support center like the Skylab Communications Center in St. Louis, or the HOSC in Huntsville is indispensable in assuring adequate coordination and crosstalk among pertinent discipline groups. Such centers should house personnel locator, support coordination, and general data review and analysis personnel.

The technical responsibility for problem analysis and workaround should remain within the original design group. This was the most important factor in the excellent response record achieved by MDAC-E during the Skylab flight. The same engineering group that had the historical design and test knowledge related to the problem at hand was the lead group in the problem solution. Their expertise allowed rapid assessment of the problem and quick determination of the solution.

Use of radio beeper signal system to avoid tedious standby procedures is highly recommended. It becomes overly restrictive and inhumane to expect key personnel to always be at a known location for a period of nine to twelve months.

Hardware breadboards of major system and component items should be provided to working groups to allow flight problem investigation on the ground. These breadboards can be made from qualification or development hardware.

7.5.3 Desirable Improvements

In the context of the previously described Mission Support capability, MDAC-E encountered major problems in two areas.

The lack of adequate paper data transmission capability was overcome only by the superior efforts of the using people. Magnafax is just not suitable to provide high quality intercenter data transmission on a timely basis. Future programs should have an LDX or data TV and printout transmission capability.

Future programs should provide the equivalent of a MOPS terminal at each support center with the ability to call up trend data and data compression (Autoscan) formats both current and historical.

SECTION 8 NEW TECHNOLOGY

Initially the Airlock was a state-of-the-art vehicle, being assembled almost entirely of space qualified, off-the-shelf hardware; as such it had a limited new technology disclosure potential. As the concept evolved into the complex spacecraft launched as SL-1, advanced state-of-the-art design, processing, and programming was required. The major milestones in advancing new technology were:

(1) Use of multiple docking ports.

(2) Adoption of a two-gas (O_2/N_2) atmosphere with lightweight storage vessels.

(3) Incorporation of the ATM with the required deployment structure and mechanisms.

(4) Use of a master caution and warning system with a variety of sensors and intricate vehicle element interfaces.

(5) The basic change from "wet" to "dry," increasing power, communications, instrumentation, crew systems, and experiment complexity.

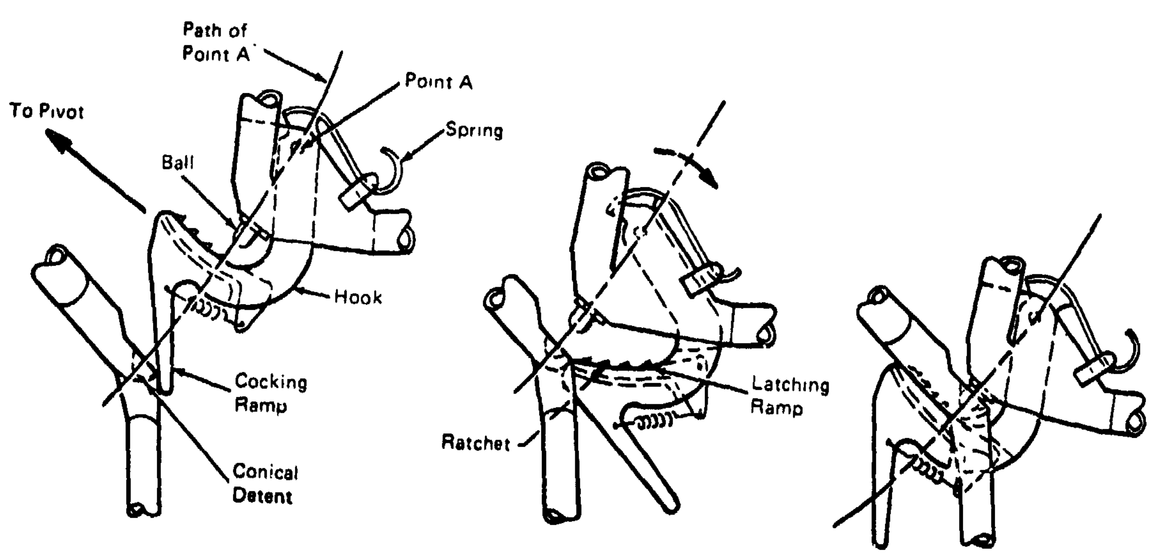
With the increased scope and complexity of the Airlock Module, a program goal of 400 disclosures was established. Under the Airlock contract, MDAC-E has submitted 451 new technology disclosures. Figure 8-1 identifies the disclosures that warranted preparation and filing of patent applications or publication of Tech Briefs. The one Airlock New Technology Disclosure which resulted in a patent application being filed by NASA is the Deployment Assembly latching mechanism shown in Figure 8-2. The highlights of the new technology program are as follows:

- Publication of 15 NASA Technology Briefs.
- Anticipated publication of additional NASA Technology Briefs.
- Patent applications prepared by NASA for three MDAC-E disclosures.
- One patent application submitted (NASA case number MFS-21606).

PUBLISHED NASA TECHNOLOGY

NASA CASE NO.	TECH BRIEF NO.	DESCRIPTION	
MFS 71203	-	THRUST ISOLATION MOUNTING	PATENT APPLICATION PREPARED
MFS 21577-1	-	RADIATION DETECTOR	
MFS 21606	B72-10457	LATCH MECHANISM	
MFS 21575	B72-10324	BAFFLE TO CONFINE GLOW DISCHARGE IN ION PUMP	TECH BRIEF PUBLISHED
MFS 21576	B72-10467	AIRLOCK CAUTION AND WARNING SYSTEM	
MFS 21716	B72-10404	CONTROLLED FLOW ASSEMBLY	
MFS 21788	B72-10576	LEAK TEST SYSTEM	
MFS 21720	B72-10639	A RANGE EXPANDING SIGNAL CONDITIONER	
MFS 21650	B72-10459	ADJUSTABLE LOCKING DEVICE	
MFS 22426	B73-10199	SILICON CONTROL RECTIFIER SEAL TESTING	
MFS 21584	B73-10235	FLAMMABILITY CONTROL FOR ELECTRICAL CABLES AND CONNECTORS	
MFS 22012	B72-10499	TANDEM STEERABLE RUNNING GEAR	
MFS 22470	B73-10082	FILAMENT WOUND STEEL LINED TANK	
MFS 21606	B72-10457	LATCH MECHANISM	
MFS 22159	B73-10089	ARTIFICIAL ATMOSPHERE CONTROL SYS	
MFS 22067	B73-10118	AN AMPERE-HOUR METER FOR BATTERIES	

FIGURE 8-1 PUBLISHED NASA TECHNOLOGY



NOTES: 1. SUBMITTED AS NASA CASE NUMBER MFS-21606
2. PATENT APPLICATION SUBMITTED

FIGURE 8-2 DEPLOYMENT ASSEMBLY LATCHING MECHANISM

Most of the disclosures have application to other aerospace programs, for example:

- Protection of pressure sensitive components in hard potting.
- Metal-lined filament-wound pressure vessel for lighter weight and greater safety.
- Caution and Warning System with ultraviolet fire detector, rapid pressure loss detector and a gas flow sensor.
- Controlled gas flow assembly for use in a wide range of temperature and pressure.
- Leak Test System for quick check of large volume pressurized compartments.
- Range expanding conditioner for increased signal resolution.

Additionally, some of the Airlock technology disclosures have the potential for other than aerospace application. For example, the following could be adapted to industrial use.

- Caution and Warning System for high speed ground transportation or industrial systems.
- Paper take-up device for unattended teleprinter unit.
- Latching mechanism capable of misaligned latching with no play in the latched position.
- Adjustable locking device capable of transporting loads.
- Computer programs for management data tracking.
- Computer programs for dynamic interaction and structural analysis.

SECTION 9 CONCLUSIONS

The Skylab Program was an extremely successful space operation - all mission objectives were achieved in spite of a serious launch anomaly.

The Airlock Module, including the Payload Shroud, the Fixed Airlock Shroud, and the ATM Deployment Assembly, effectively supported the Skylab cluster throughout the mission, including the off-nominal environmental conditions encountered through the first days of the SL-1/2 mission and the extension of the SL-4 mission. The mission success of the Airlock Module, including its Mission Operation Support, is an excellent indicator of the effectiveness of the total Airlock technical program.

Mission performance of the Airlock systems was outstanding; all mission requirements were met. Designed-in system flexibility and redundancy, pre-planned contingency procedures, and real time work-arounds were adequate for recovery from those system discrepancies that did occur.

At the end of mission, the Airlock systems were still capable of effective Skylab support; no significant function had been lost.

Lessons were learned from the Skylab Program that have applicability to other space programs, however, caution must be exercised in tailoring those "Lessons Learned" to other programs which might have significantly different philosophy and program constraints.

9.1 AIRLOCK MISSION PERFORMANCE

The Airlock systems effectively supported the Skylab mission by meeting all its mission requirements and performing all assigned functions. This support included the first twelve days, prior to parasol erection, when the Airlock systems were exposed to off-nominal low temperatures and AM hardware installed or stowed in the OWS exposed to off-nominal high temperatures. It also included the additional 13 days of low power operation prior to release of SAS #1. Additionally, the Airlock systems provided continued effective support for the 29-day mission extension of SL-4; the incorporation of the Comet Kohoutek experiment was readily accommodated during SL-4.

Evaluation of the mission impact of Airlock hardware discrepancies indicates that none of them had any negative effect on crew safety, planned mission duration, experiment accomplishment, or vehicle habitability.

Appendix E is a detailed status of the fifty-one (51) significant Airlock hardware discrepancies that occurred during the Skylab mission.

9.2 AIRLOCK END-OF-MISSION SYSTEM STATUS

All Airlock systems were fully operational at the end-of-mission. The system discrepancies that remained were relatively insignificant and had no effect on the capability to adequately support all mission objectives.

In summary, Airlock end-of-mission system status was:

- Structural/Mechanical System was fully operational with no reported discrepancies.
- Thermal Control System was fully operational with ATM C&D Panel/EREP cooling loop flow fluctuation the only discrepancy. Loop cooling was adequate and periodic system deaeration with liquid/gas separator would restore full flow.
- Environmental Control System was also operating normally with an occasional QD leakage on gas side of Condensate System being the only discrepancy. Problem was correctable by QD reconnection or capping.
- EVA/IVA System was working perfectly with no problems. Leakage of SPT's LSU/PCU composite quick disconnect during last EVA depleted SUS #1 reservoir; system would have required reservicing prior to next usage.
- Electrical Power System was fully operational - total mission performance was exceptional with no anomalies reported.
- Sequential System functioned successfully during SL-1/2 and was deactivated as planned.
- Instrumentation System was operating normally with existing discrepancies having no effect on the capability to fully support the mission.
- Communication System was also operating adequately - system redundancies and work-arounds effectively recovered full capability of the system.
- C&W System was fully operational except for one parameter which was not critical to mission continuation.
- Crew Systems were fully operational and capable of providing required crew support.

Appendix F is a detailed end-of-mission status of all Airlock systems.

9.3 AIRLOCK PROGRAM "LESSONS LEARNED"

Each section of this report discusses conclusions that may be reached and recommendations that can be made concerning each subject system or engineering activity. These conclusions and recommendations were retained as presented by the various technical groups to insure a complete and objective documentation.

In addition, these conclusions/recommendations were reviewed and evaluated for their specific applicability to future program usage. These significant "Lessons Learned" were divided into four categories:

A. General Program Activities - Philosophy, requirements, reviews, documentation, etc., that warrant discussion.

B. Systems/components/procedures that proved highly effective and that are prime candidates for future space program usage.

C. Systems/components/procedures that were identified where design improvements or changes should be considered to increase performance and/or reliability during future usage.

D. Systems/components/procedures that were identified where design changes are required prior to consideration for future space usage.

It should be noted that the "Lessons Learned" from any program must be considered in context with that program's philosophy and constraining ground rules, such as:

- Funding level and schedule.
- Program milestone schedule.
- System performance requirement level, i.e., required increase in state-of-the-art performance.
- Hardware usage philosophy, i.e., new design equipment versus off-the-shelf equipment.
- Stability of program objectives and system requirements.
- System verification concept.

Evaluation of an Airlock "Lesson Learned" for applicability to a future space program must be made on an individual basis and must include a review of all available alternatives. Obviously, not all of the Airlock Program lessons will be applicable to a program that has a different philosophy and

significantly different program constraints. With this note of caution in tailoring their use to new applications, the significant "Lessons Learned" on the Airlock Program were:

A. General Program Activities

(1) The program philosophy of maximum use of existing, qualified space hardware with extensive use of system engineering analyses and previous test results to identify the minimum supplemental test program required to complete system verification was proven as a valid, economical approach to a successful mission.

- A blanket philosophy requiring the use of existing "qualified hardware" may be misleading. Best engineering judgement must be used in projecting cost saving versus required compromises in interfacing design, system operation and future availability of such hardware. Considerable cost, lead time and vendor coordination was required on "qualified hardware" that had been phased out of production.

(2) The careful choice of high quality, commercially available hardware for upgrading to manned spacecraft application minimized the delay in achieving flightworthiness. New designs usually have new problems, whereas, starting from a good existing design may minimize these development problems.

(3) The use of the modular design concept proved very effective, i.e., electronics modules, suit/battery cooling module, ECS coolant pump module, etc. This approach permitted assembly and complete module checkout testing prior to final spacecraft installation.

(4) Significant cost savings were achieved by elimination of the conventional low fidelity vehicle tube and cable mock-up. Use of the flight article for this purpose eliminated the inevitable problems resulting from transition between mock-up and flight system installations. However, high fidelity tube and cable mock-ups of complex equipment modules were used to good advantage in areas of significant congestion.

(5) Trainers were a very effective part of the Airlock Program. These trainers -- Zero-G, One-G, and Neutral Buoyancy -- were utilized:

- To provide early definition of crew system requirements.

- To allow early crew evaluation of crew system design -- interior arrangement, panel design, lighting and color evaluation, accessibility verification, etc.
- To provide a mock-up of the total vehicle and allow early visualization of system configuration and interfaces.
- To develop crew procedures.
- To conduct crew training.

In addition, these trainers were especially valuable during the mission in the development of contingency crew activities, i.e., thermal shield erection, SAS #1 Wing release, gyro six-pack installation, etc.

(6) The Airlock System Test Units - ECS/TCS STU and I&C STU (STU/STDN) - were very desirable mission support items. They were effectively used both to aid in troubleshooting and to develop and verify new flight procedures. In addition, these units were used prior to the mission to verify subsystem interfaces and develop flight procedures.

Also, the STU/STDN, because of its flight data link, gave rapid access to selected flight data and greatly enhanced the mission support effort.

(7) Basic program requirements such as the Cluster Requirements Specification (RS003M00003) should be developed early in the design definition phase and requirement changes should be minimized. Late definition of new system and hardware requirements are costly.

(8) More commonality between NASA centers on specifications and requirements is desirable to minimize the problems between interfacing systems or modules.

(9) Imposition of specifications and the degree of compliance required should be carefully considered to minimize the cost associated with satisfying unrealistic requirements, for example:

- Lighting Level Requirements should be specified only as a guide. Because the arrangement and color of surrounding walls and equipment greatly affect the required amount of light, it is desirable

to use a lighting mockup to allow early crew assessment of lighting system adequacy.

- Touch Temperature Specifications should be revised to be more realistic, i.e., they should be based on type of surface and likelihood of crew contact.
- Environmental Qualification Tests should be reviewed to insure realistic requirements. An original Airlock requirement was for material to be non-nutrient to fungus growth as verified by testing per Paragraph 4.8 of MIL-B-5272C. Subsequently, it was determined that spacecraft contamination and environmental control procedures effectively prevented fungus growth. Acceptance of this rationale eliminated the need for a costly and unnecessary test program.

(10) The material selection and verification criteria for non-metallics should be established early in the program. Material selection should place strong emphasis on prior test results and, if new or unusual material usage is anticipated, an early test program should be planned.

(11) Interface requirements should be established and documented in advance of firm system design release to minimize the redesign required when the interface requirements are coordinated and base-lined after-the-fact.

- ICD's should show only the information required to control the interface requirements.
- Electrical interface control specifications should be established for end-to-end definition of all power, control or signal lines crossing a module interface. Function description at intermediate connectors should be omitted.
- Electrical power quality requirements should be defined as early in the program as possible to permit orderly and economical systems development.

(12) An effort should be made to minimize the number of major reviews and to maximize review effectiveness. For example, due in part to the length of the program and the changes in mission requirements, the Airlock program had a number of special hardware reviews:

- Critical Mechanisms Review.
- Systems/Operations Compatibility Review.
- Safety Checklist Review.
- Hardware Integrity Review

Inclusion of the objectives of these special reviews into the regular review program would provide the NASA with a more effective assessment of the system development/verification cycle.

(13) Eliminate the redundancy in documents that convey similar information in a slightly different form, i.e., G499 Acceptability Review and E935 Qual Status Report and the various computer reports which summarized hardware status.

(14) The use of program peculiar parts identifiers (AM suffix) effectively controlled piece part shortages by eliminating inadvertent usage by other programs and simplifying "alert" scanning activities. This procedure eliminated the need for specially controlled project stockrooms.

(15) Analytical programs developed early for use in systems design should include enough flexibility to also be used during the mission support phase, i.e., launch load analysis program, structural analysis programs, environmental system analysis programs, etc.

(16) Based on the flight proven adequacy of the Airlock Module structural design and the development of complex computer programs, and the proficiency in their use, it is recommended that future spacecraft structure be verified primarily by analysis. Sufficient confidence can be gained by performing simple component tests and possibly low load level tests on the flight article. The Airlock Module was originally static tested to the early 9200 pound "Wet Workshop" configuration and loading conditions; subsequently, the integrity of the structural changes required for the heavier (16,900 lbs) "Dry Workshop" configuration was verified by analysis.

(17) A central clearing point in each support center, such as the Skylab Communications Center in St. Louis or the HOSC at MSFC, is very desirable to assure effective coordination and timely data response between pertinent technical groups during mission support activities.

(18) Identification of flight, inert, and spent ordnance items should be standardized for all contractors and government agencies.

B. The Airlock Program verified the effective space operation of several systems and components that are high-potential candidates for usage on future programs.

(1) The molecular sieve system provided reliable, effective CO_2 and odor control.

(2) The teleprinter was an invaluable tool in providing hard copy data updates to the crew.

(3) The Airlock Electrical Power System provided effective power conditioning and distribution. System control flexibility greatly enhanced the capability of the power system.

(4) The C&W system memory capability was very useful in after-the-fact fault identification.

(5) The capability of composite tanks, i.e., thin metallic liner with thick fiberglass wrapped outer layer, for high pressure storage of gases in space was verified.

(6) The ordnance actuated free thrusting joint concept and the ordnance actuated pin puller design provided positive, contamination free operation.

(7) The Airlock two-gas control system provided safe, effective PPO_2 control for entire Skylab cluster.

(8) Condensing heat exchangers with fritted glass water separator plates provided effective water removal capability. Water separator plates functioned throughout the mission without planned periodic changeout.

(9) Installation of temperature control valves in series effectively provided preferential cooling to selected component groups.

(10) Radiator/thermal capacitor performance was effective even in ZLV orientation (EREP operation) at higher Beta angles than initially planned -- no significant performance degradation occurred in this 270-day mission.

(11) Passive thermal control concept of coatings, insulation and single layer thermal curtains performed as planned and verified the adequacy of extensive thermal analysis/limited test approach.

(12) The hatch latch mechanism functioned without problems both in its original configuration on the EVA hatch and in a modified configuration on the internal hatches. This proven latch system is easily adaptable to varying hatch requirements and should be considered for future usage.

(13) The silicone rubber seals used in the internal and EVA hatches functioned without leakage or apparent degradation. These seals were fabricated with the latest silicone rubber processes.

(14) The technical responsibility for mission performance evaluation and problem analysis should remain with the original design groups -- this approach was very effective during Airlock mission support.

C. The Airlock Program identified several desirable design improvements, system changes or test program changes that would enhance the performance and/or reliability of future space programs:

(1) In-flight maintenance and hardware replacement proved to be much easier than anticipated; therefore, where feasible, provisions should be made for in-flight repair and/or replacement of components.

(2) External vehicle design should include provisions such as universal attach receptacles for mating foot restraints, handholds, umbilical restraints, portable lights, etc., for contingency EVA activity.

(3) Panel installations should be made more accessible so that the entire panel need not be removed in order to replace detail components.

(4) Panel indicator lights should be replaceable from front of panel.

(5) Circuit breakers should be located and protected so that accidental tripping by the crew is minimized.

(6) Minimizing of acoustical feedback should be considered when developing vehicle communication system requirements.

(7) Switching of electrical ground return lines for system control should be avoided.

(8) Standard power distribution guidelines should be imposed on all module contractors. For example:

- Twisted pair power and return wires.
- Wire or structural return paths (but not both).
- Wire and C/B derating criteria.
- Switch operational positions - up is "ON", down is "OFF".

(9) Fluid and gas systems should be designed with internal provisions for inflight reservicing - if possible, GSE servicing ports should be designed and located to provide this capability.

(10) Use of brazed systems in lieu of B-nuts is desirable to eliminate potential fluid leak sources.

(11) Use of flexible metal hoses should be limited to applications that must accommodate relative motion between interconnected modules. In general, hardline installations will satisfy most applications.

(12) Use of quick disconnects should be limited to critical crew activities - less critical requirements should utilize a more positive mechanical connector, i.e., one less sensitive to installation alignment and sideloading.

(13) Increased standardization of nonmetallics is a desirable goal -- would allow more thorough testing of smaller specimen group.

(14) The compatibility of a system fluid with all system materials, both metallic and nonmetallic, and system components (pumps, valves, QD's, etc.) should be verified by an all-up system test as early in the program as possible -- testing should include all operational modes including dormancy.

(15) Flight articles with complex surface configurations that preclude visual inspection of rain sealing provisions should receive a complete rain test to verify no leakage.

(16) Critical components with complex characteristics should have early prototype parametric testing for support of system design. For example, prototype NiCad Battery testing provided early insight into battery characteristics.

(17) Minimize differences between vendor acceptance test and in-house pre-installation acceptance test setups and procedures to preclude the uncertainty over differing test results.

(18) In all test procedures that involve the measurement of electrical power, the current or wattage should be taken and recorded through the vehicle voltage range in 1 or 2 volt increments. Power measurements should be made in all operating modes and simulate actual flight conditions as close as possible.

(19) Cleaning techniques used on items, such as heat exchangers with complex internal passages, should be improved to minimize potential system contamination. In addition, fabrication procedures should be improved to minimize the generation of trapped particles.

(20) For future design of long linear explosive systems, the addition of adjustable length tubes or adjustable locations of detonator blocks should be considered to allow greater tolerance on linear explosive assembly lengths.

(21) Use of improved tubing connections for transfer and manifold tubing in linear explosive systems should be considered to reduce the assembly and retorque effort required to provide a leak tight system. Payload Shroud required multiple torque applications.

(22) It is desirable that the lock compartment for EVA not separate or isolate one part of the vehicle from another.

(23) It is desirable to establish, early in the design definition phase, a standard coordinate system for all modules and for usage by all disciplines.

(24) Future programs should maintain an LDX or data TV and printout transmission capability between mission operation support centers because commercial facsimile transmission is unsatisfactory for fine detail and transmission time is not fast enough.

(25) Future programs should also provide the equivalent of a MOPS terminal at each support center with the ability to call up trend data and data compression (autoscan) formats, both current and historical.

The Airlock Program also identified some components/systems that require design change prior to being utilized in future programs:

(1) The liquid system flowmeters used were relatively delicate instruments that were susceptible to jamming due to contamination and to bearing failure due to overspeeding. It is recommended that a more rugged flowmeter be developed for future programs.

(2) The gas system flowmeters used were susceptible to contamination and to variation in the duct flow. It is recommended that the flowmeters be installed in long, straight duct sections with upstream filters or that a less sensitive flowmeter be developed.

(3) A ΔP transducer failed, prior to launch, due to water leakage through the transducer diaphragm caused by long exposure to the water system. Replacement of the diaphragm with one that is more compatible with water system exposure is required prior to future usage.

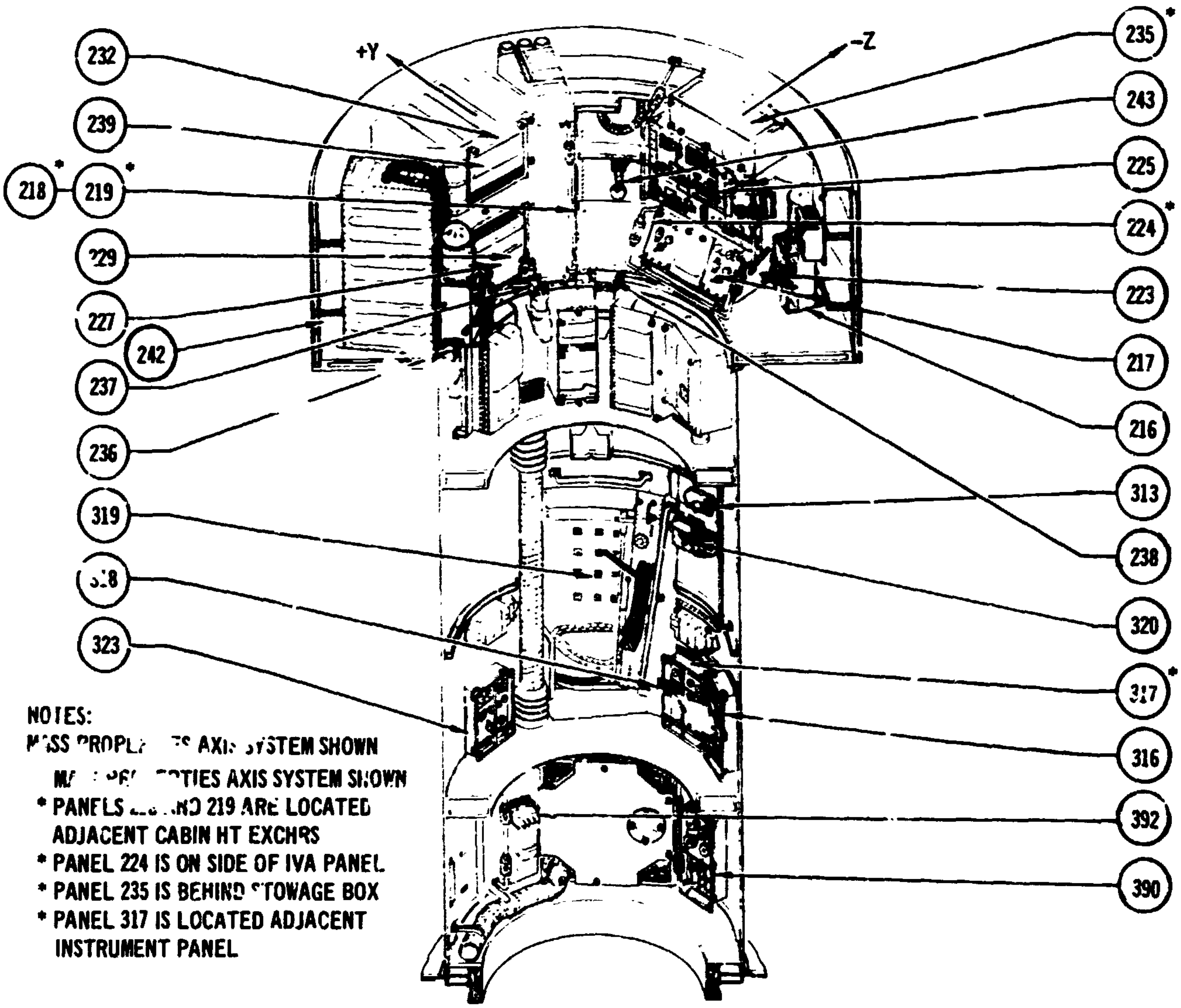
(4) The temperature control valves (TCV) were precision devices with close fitting internal parts which made them susceptible to loop contamination. It is recommended that TCV be protected with filters and bypass relief valves or be redesigned to increase internal clearances and minimize sensitivity to contamination.

(5) The $PPCO_2$ detectors used were sensitive to changes in pressure, gas flow, and nitrogen level and had a zero shift frequency with extended operation. It is recommended that a different type of $PPCO_2$ detector be used.

(6) A water storage tank bladder failed prior to launch from degradation due to water solution exposure, cycling, and drying. Although tanks with newly installed bladders successfully performed the mission, it is recommended that a new bladder material be developed for long duration missions.

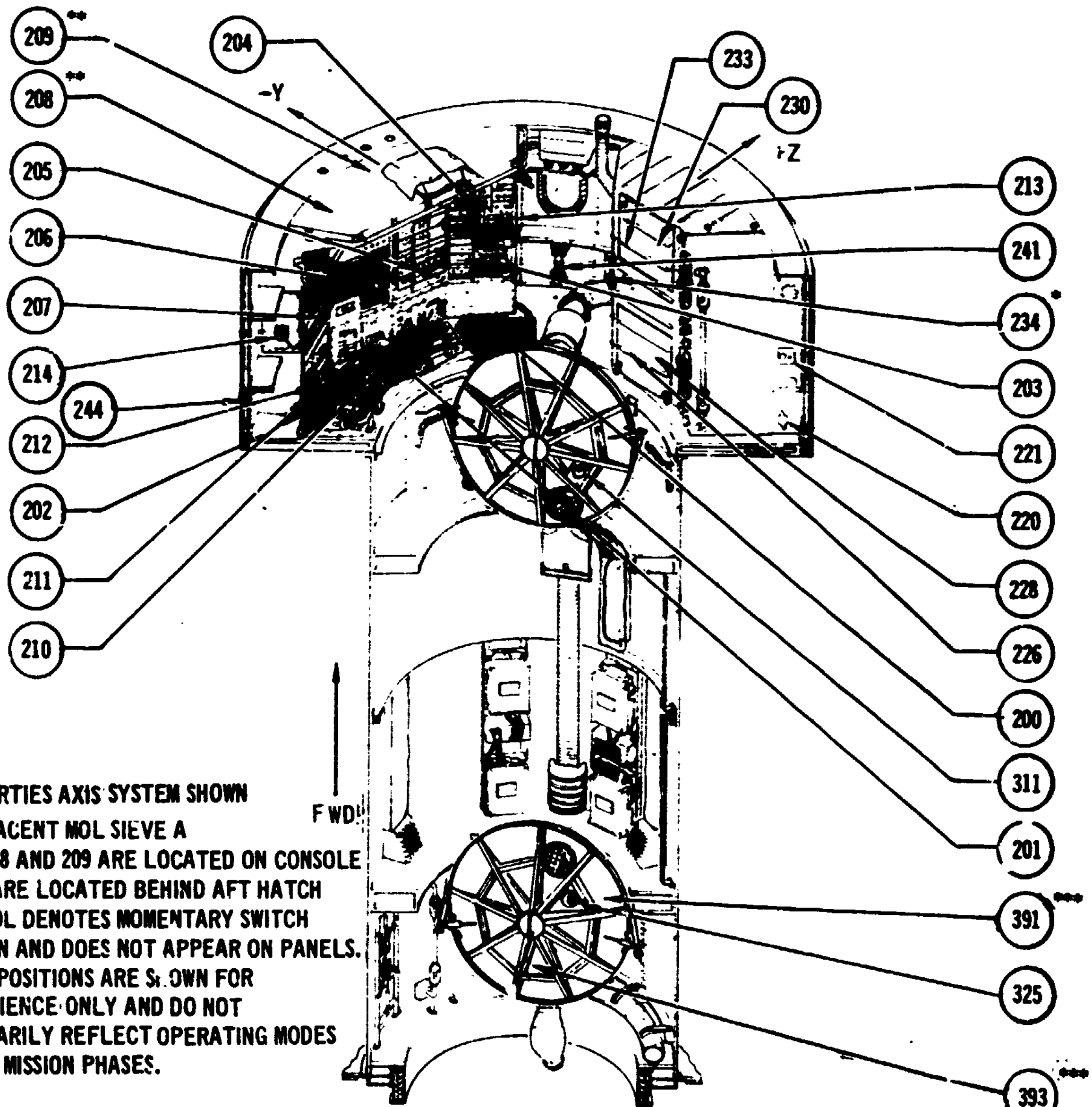
APPENDIX A

AIRLOCK CONTROL AND DISPLAY PANELS



NOTES:
MASS PROPL... AXIS SYSTEM SHOWN
MA... ...TIES AXIS SYSTEM SHOWN
* PANELS ... AND 219 ARE LOCATED ADJACENT CABIN HT EXCHRS
* PANEL 224 IS ON SIDE OF IVA PANEL
* PANEL 235 IS BEHIND STOWAGE BOX
* PANEL 317 IS LOCATED ADJACENT INSTRUMENT PANEL

AIRLOCK PANEL LOCATIONS



NOTES:
MASS PROPERTIES AXIS SYSTEM SHOWN
* 234 IS ADJACENT MOL SIEVE A
** PANELS 208 AND 209 ARE LOCATED ON CONSOLE
*** 391 & 393 ARE LOCATED BEHIND AFT HATCH
1. SYMBOL DENOTES MOMENTARY SWITCH POSITION AND DOES NOT APPEAR ON PANELS.
2. SWITCH POSITIONS ARE SHOWN FOR CONVENIENCE ONLY AND DO NOT NECESSARILY REFLECT OPERATING MODES AND/OR MISSION PHASES.

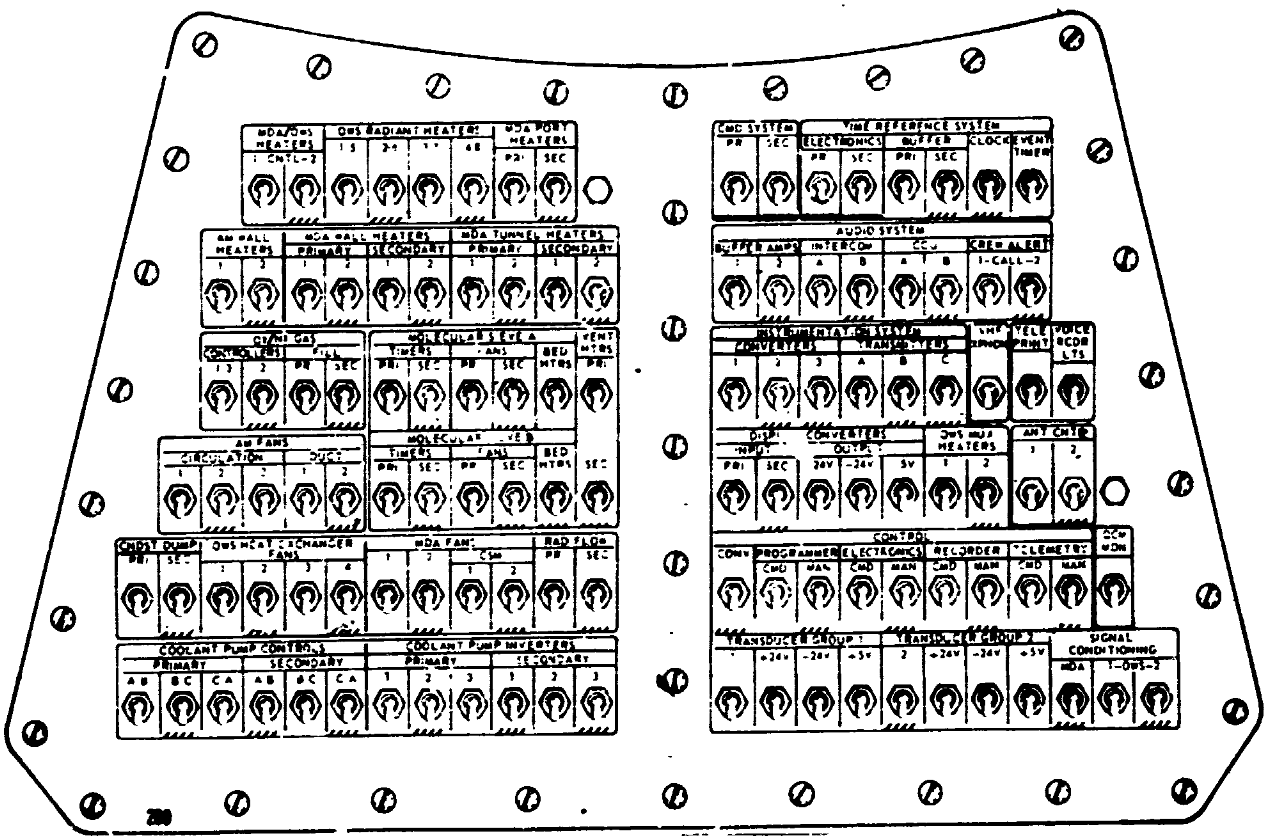
SWITCH TYPE

LEVEL LOCK TOGGLE LEVEL LOCK (GEMINI "B")

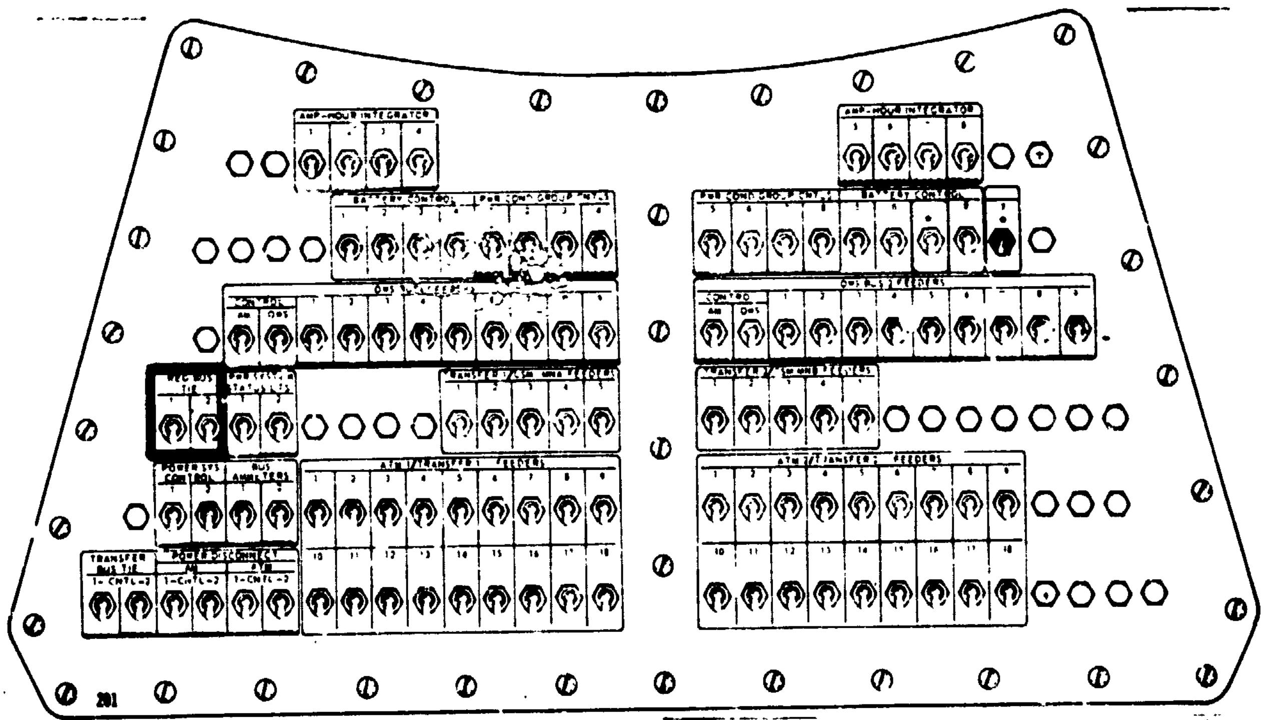
AIRLOCK PANEL LOCATIONS

PANEL NO.	NOMENCLATURE	APPENDIX PAGE	PANEL NO.	NOMENCLATURE	APPENDIX PAGE
200	CIRCUIT BREAKER PANEL (ECS, I&C)	A-5	232	MOLECULAR SIEVE B HEAT EXCHANGE, VALVES PANEL	A-16
201	CIRCUIT BREAKER PANEL (EPS)	A-5	233	MOLECULAR SIEVE A AIRFLOW VALVE PANEL	A-16
202	CIRCUIT BREAKER PANEL (EXP, LTG, EVA, TACS, C&W, SEQ)	A-5	234	MDA/OWS AIR SELECTOR VALVE	A-16
203	CONTROL PANEL (ECS)	A-7	235	ATM COOLANT RESERVOIR PRESS VALVE	A-16
204	CONTROL PANEL (I&C)	A-7	236	FIRE SENSOR CONTROL PANEL	A-16
205	CONTROL PANEL (EPS)	A-8	237	FIRE SENSOR CONTROL PANEL	A-16
206	CONTROL PANEL (EPS, C&W)	A-9	238	FIRE SENSOR CONTROL PANEL	A-16
207	CONTROL PANEL (LIGHTING, C&W)	A-10	239	MOLECULAR SIEVE B AIRFLOW VALVE PANEL	A-16
208	CONTROL PANEL (PROTON SPECTROMETER)	A-11	241	STS WINDOW CRANK -Z	A-16
209	CONTROL PANEL (TELEPRINTER)	A-11	242	STS WINDOW CRANK -Y	A-16
210	PCG CONTROL SCHEMATIC	A-12	243	STS WINDOW CRANK +Z	A-16
211	BUS DISTRIBUTION SCHEMATIC	A-12	244	STS WINDOW CRANK +Y	A-16
212	GMT CLOCK	A-12	300	FORWARD COMPARTMENT PRESSURE RELIEF VALVE	A-17
213	UTILITY POWER 1 OUTLET	A-12	303	HX PLATE SERVICING	A-17
214	UTILITY POWER 2 OUTLET	A-12	311	FORWARD HATCH PRESSURE EQUALIZATION VALVE	A-17
216	CONTROL PANEL (CONDENSATE)	A-13	312	FORWARD HATCH HANDLE	A-17
217	CONTROL PANEL (IVA)	A-13	313	LOCK COMPARTMENT PRESSURE RELIEF VALVE	A-17
218	MOL SIEVE B VENT VALVE	A-13	316	CONTROL PANEL (EVA SUPPORT)	A-18
219	UTILITY POWER OUTLET 3, (MOL SIEVE B BED CYCLE N_2 SUPPLY VALVE)	A-13	317	CONTROL PANEL (EVA NO. 1 SUIT UMBILICAL SYSTEMS)	A-18
220	MOLE SIEVE A VENT VALVE	A-13	318	LOCK DEPRESSURIZATION VALVE	A-17
221	UTILITY POWER OUTLET 4, (MOL SIEVE A BED CYCLE N_2 SUPPLY VALVE)	A-13	319	EVA HATCH	A-19
223	SYSTEM 1 LCG RESERVOIR PRESS VALVES	A-13	320	TV STATION	A-19
224	SYSTEM 2 LCG RESERVOIR PRESS VALVES	A-13	321	CONTROL PANEL (EXTENDIBLE BOOM)	A-19
225	O_2/N_2 CONTROL SYSTEM PANEL	A-14	323	CONTROL PANEL (EVA NO. 2 SUIT UMBILICAL SYSTEMS)	A-19
226	MOLECULAR SIEVE A VALVE CONTROL	A-15	325	AFT HATCH	A-17
227	MOLECULAR SIEVE B VALVE CONTROL	A-15	326	AFT HATCH HANDLE	A-17
228	MOLECULAR SIEVE A ADSORB/DESORB VALVE	A-15	390	CONTROL PANEL (M509 BOTTLE RECHARGE)	A-20
229	MOLECULAR SIEVE B ADSORB/DESORB VALVE	A-15	391	AFT COMPARTMENT PRESSURE RELIEF VALVE	A-17
230	MOLECULAR SIEVE A HEAT EXCHANGE, VALVES PANEL	A-16	392	FIRE SENSOR CONTROL PANEL	A-16
			393	CONDENSATE DUMP PORT	A-20

CONTROL AND DISPLAY PANEL REFERENCE

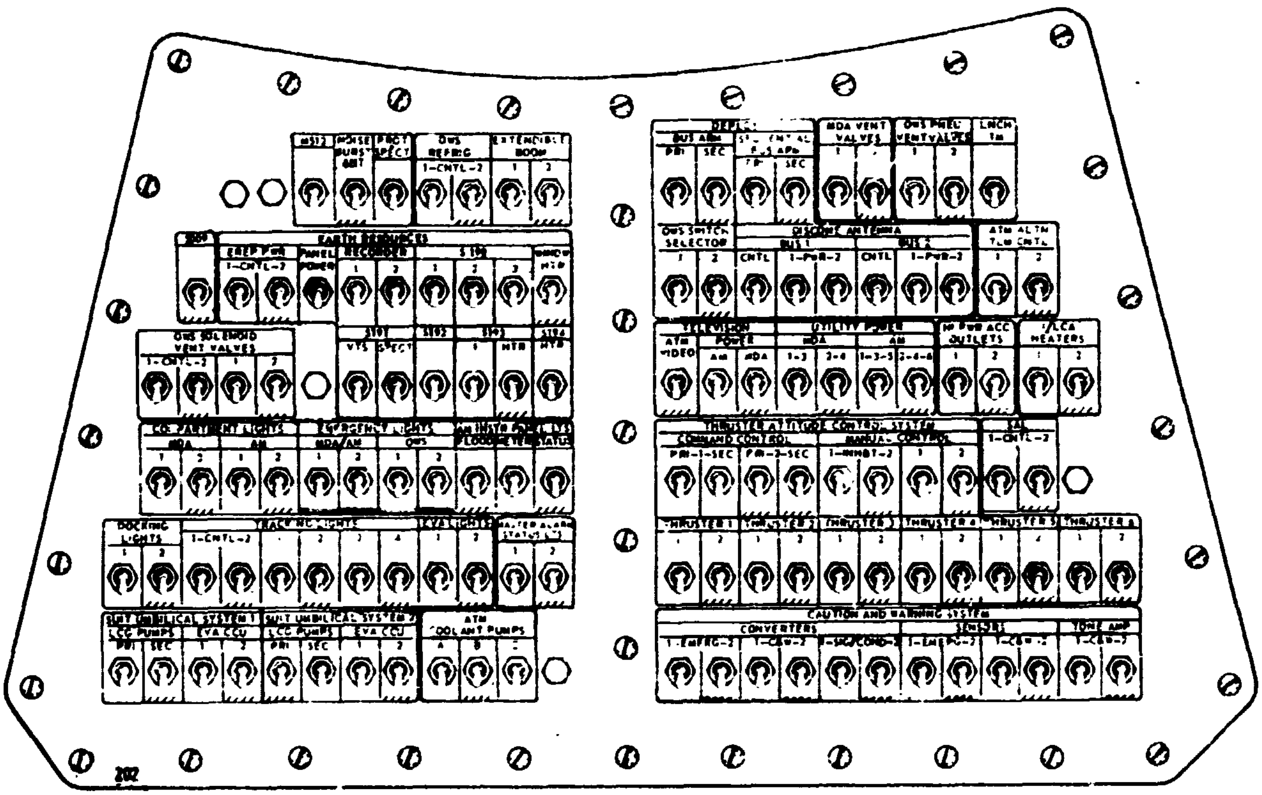


AM CIRCUIT BREAKER PANEL (ECS, I AND C) 200



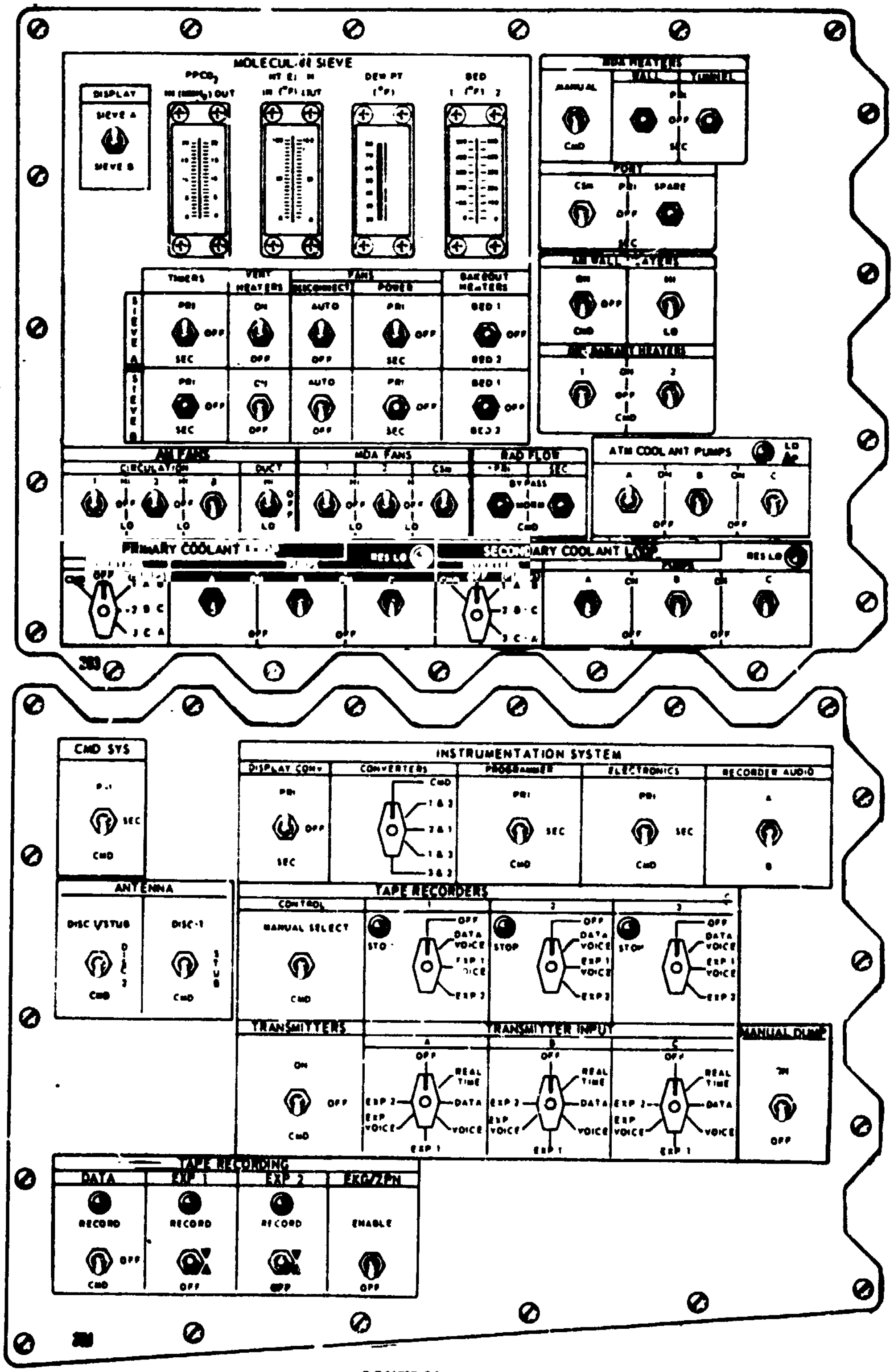
AM CIRCUIT BREAKER PANEL (EPS) 201

PANELS 200 AND 201



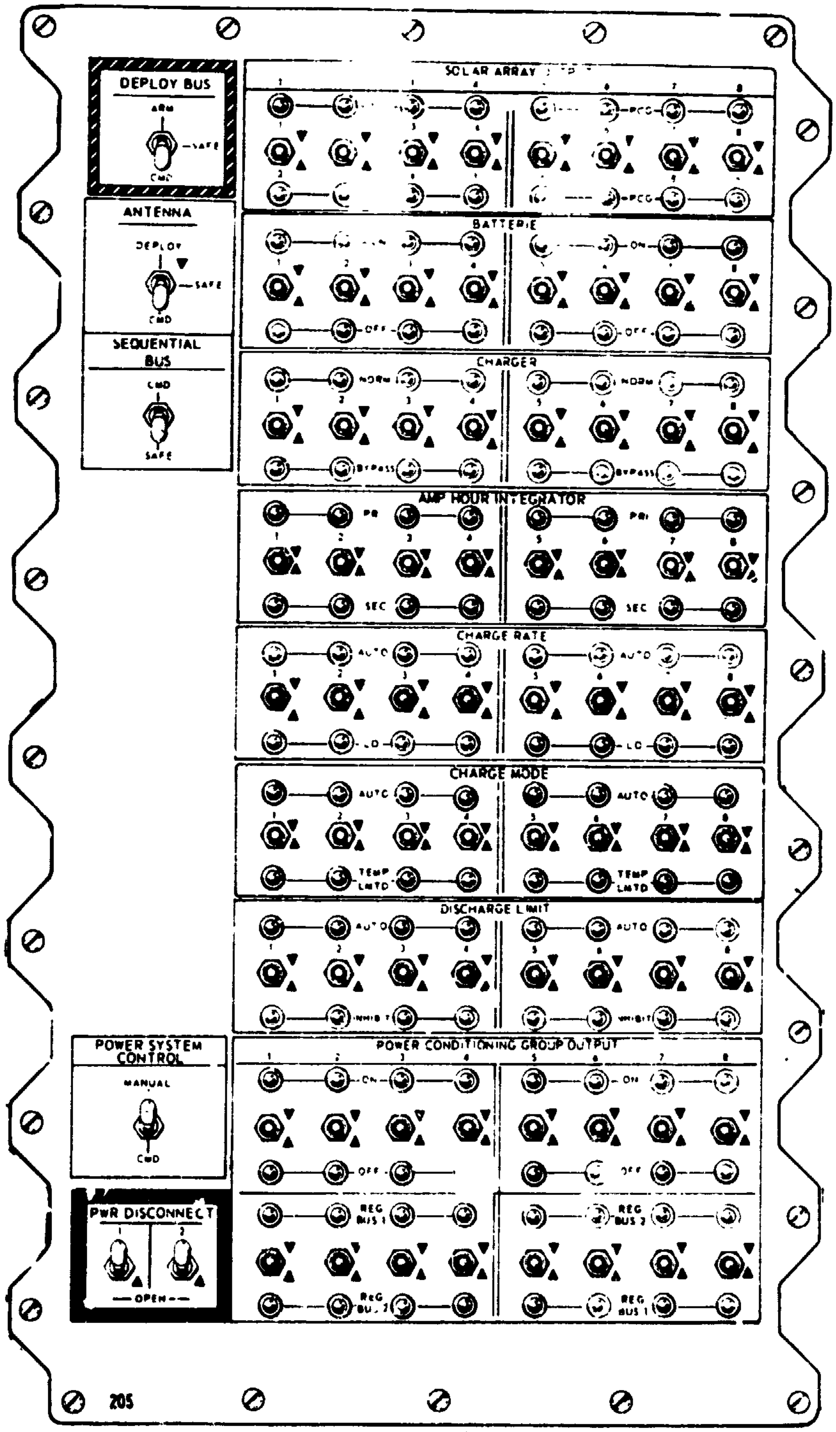
AM CIRCUIT BREAKER PANEL (EXP, LTG, EVA, TACS, CAW, SEQ) 202

PANEL 202



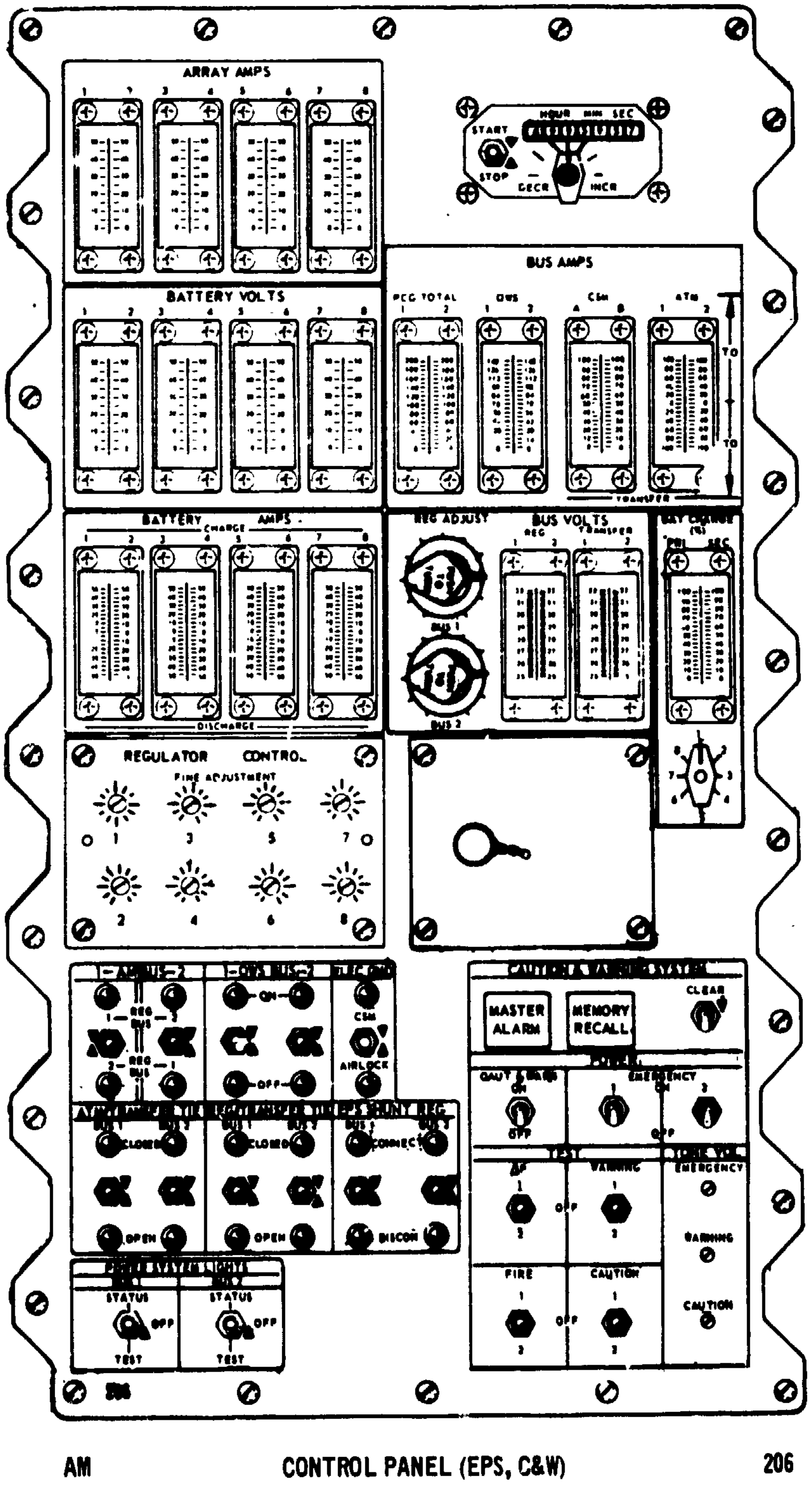
AM CONTROL PANEL (I&C) 204

PANELS 203 AND 204



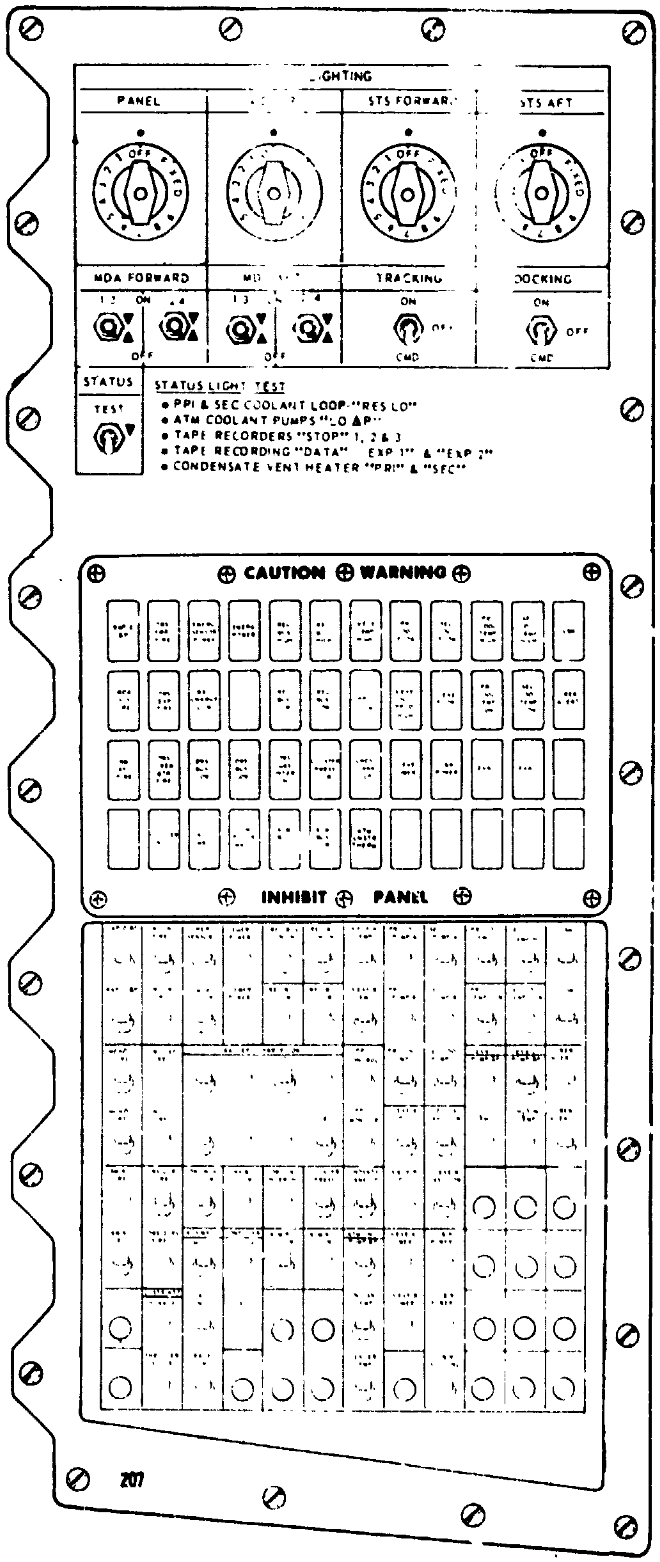
AM CONTROL PANEL (EPS) 205

PANEL 205



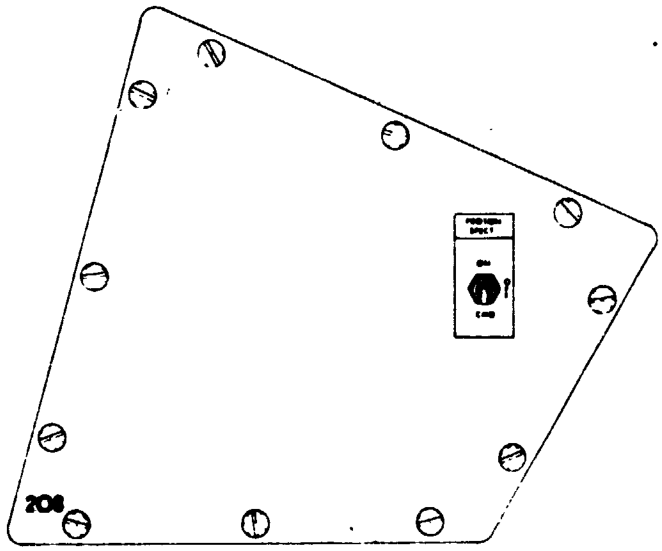
AM CONTROL PANEL (EPS, C&W) 206

PANEL 206

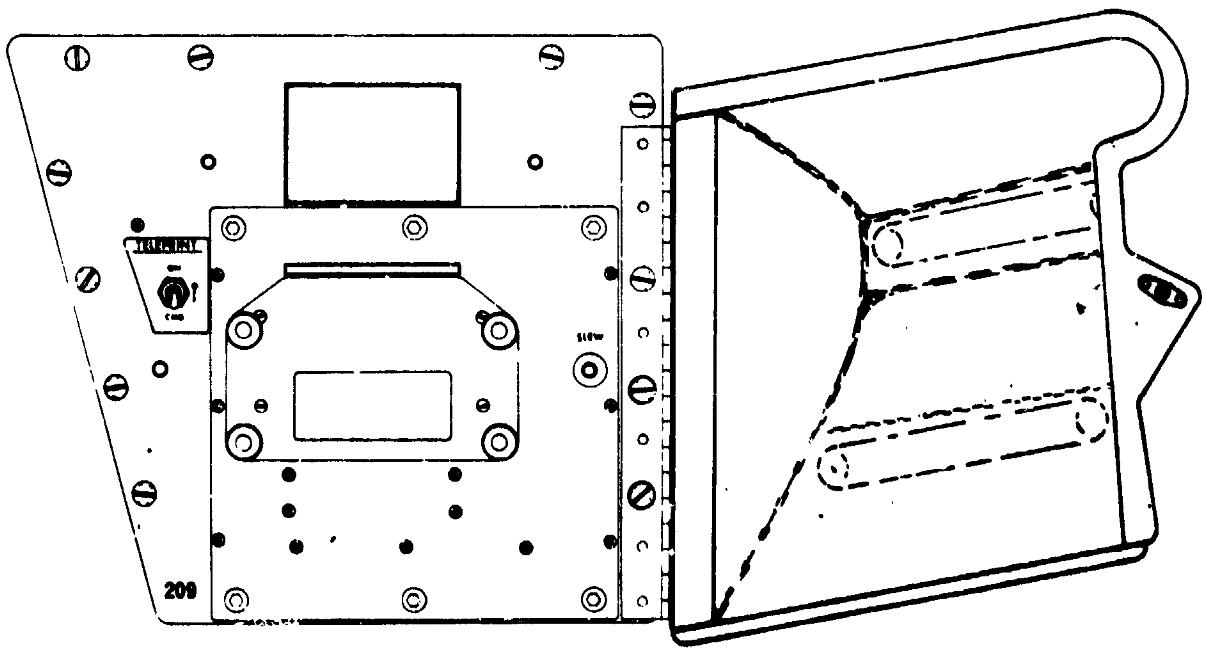


CONTROL PANEL (LIGHTING, C&W)

PANEL 207

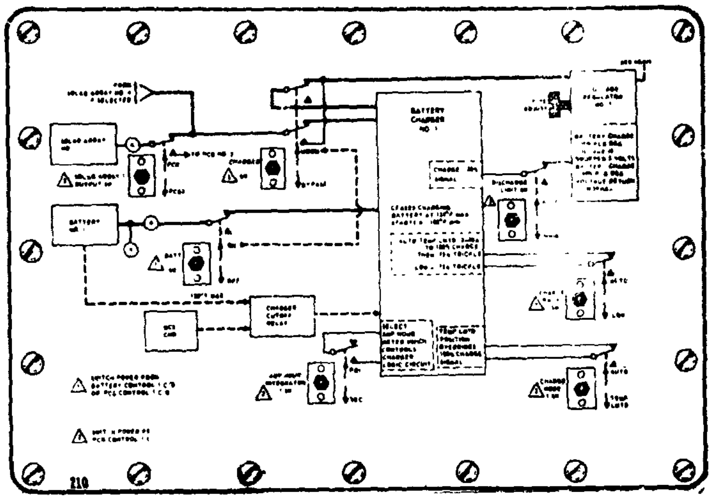


AM CONTROL (PROTON SPECTROMETER) 208

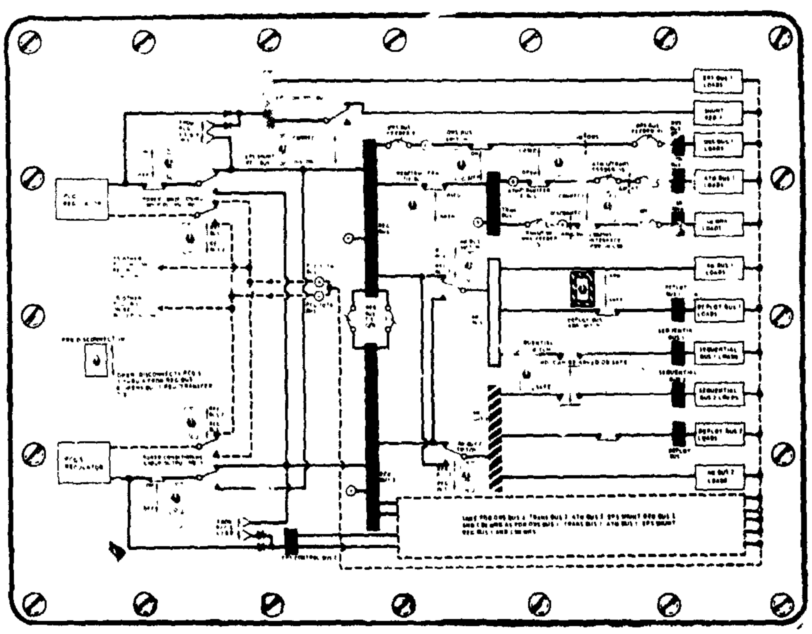


AM CONTROL PANEL (TELEPRINTER 209

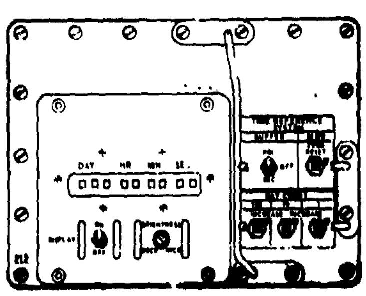
PANELS 208 AND 209



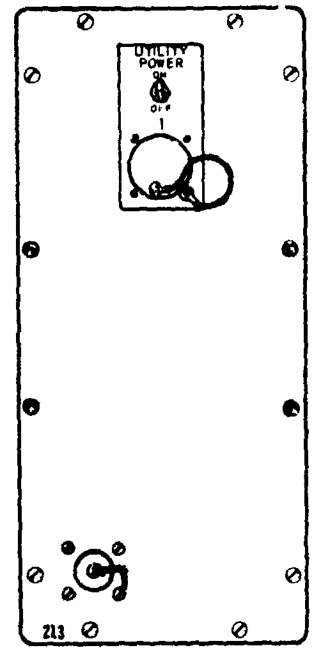
AM PCG CONTROL SCHEMATIC 210



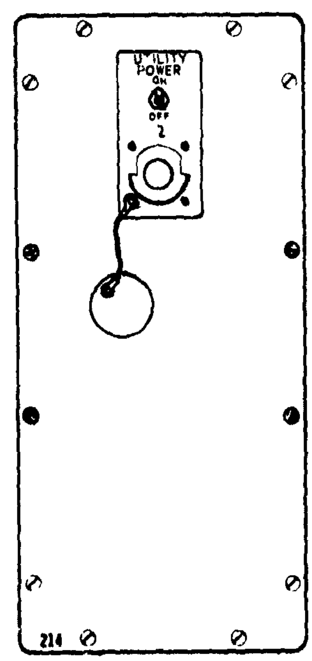
AM BUS DISTRIBUTION SCHEMATIC 211



AM GMT CLOCK 212

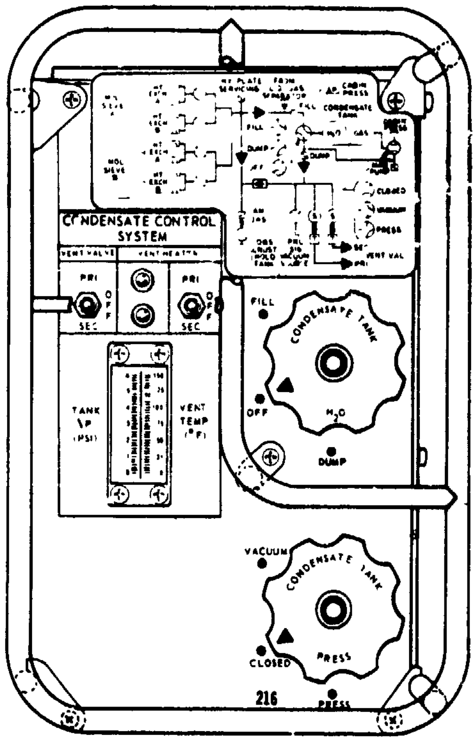


AM 213
UTILITY POWER I OUTLET



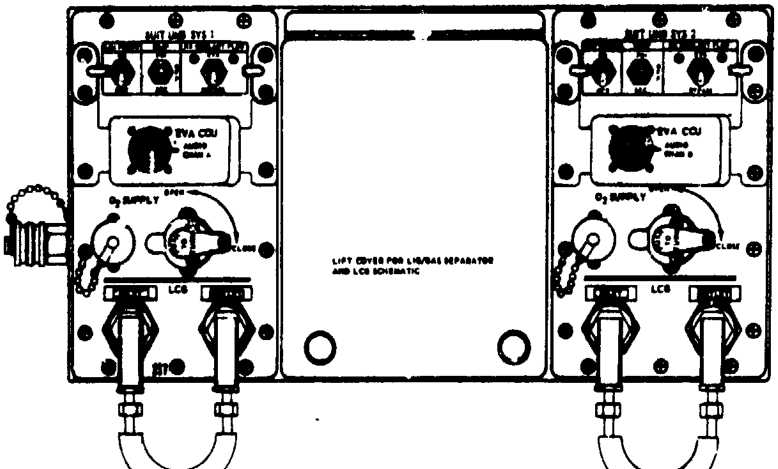
AM 214
UTILITY POWER 2 OUTLET

PANELS 210, 211, 212, 213, AND 214

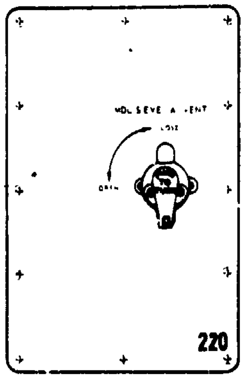


AM 216

CONDENSATE MODULE CONTROL PANEL

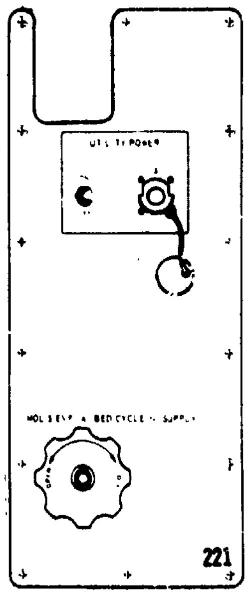


AM IVA CONTROL PANEL 217



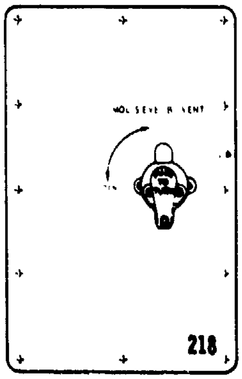
AM 220

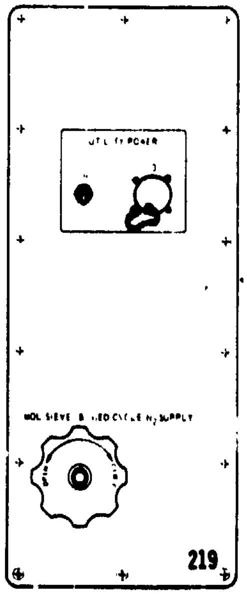
MOL SIEVE A VENT VALVE

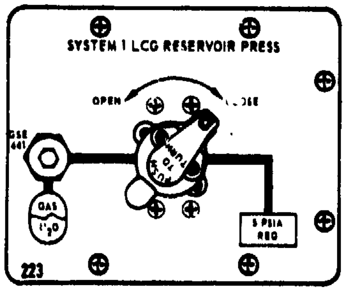


AM 221

UTILITY POWER OUTLET 4 AND MOL SIEVE A BED CYCLE N_2 SUPPLY VALVE







AM 218

MOL SIEVE B VENT VALVE

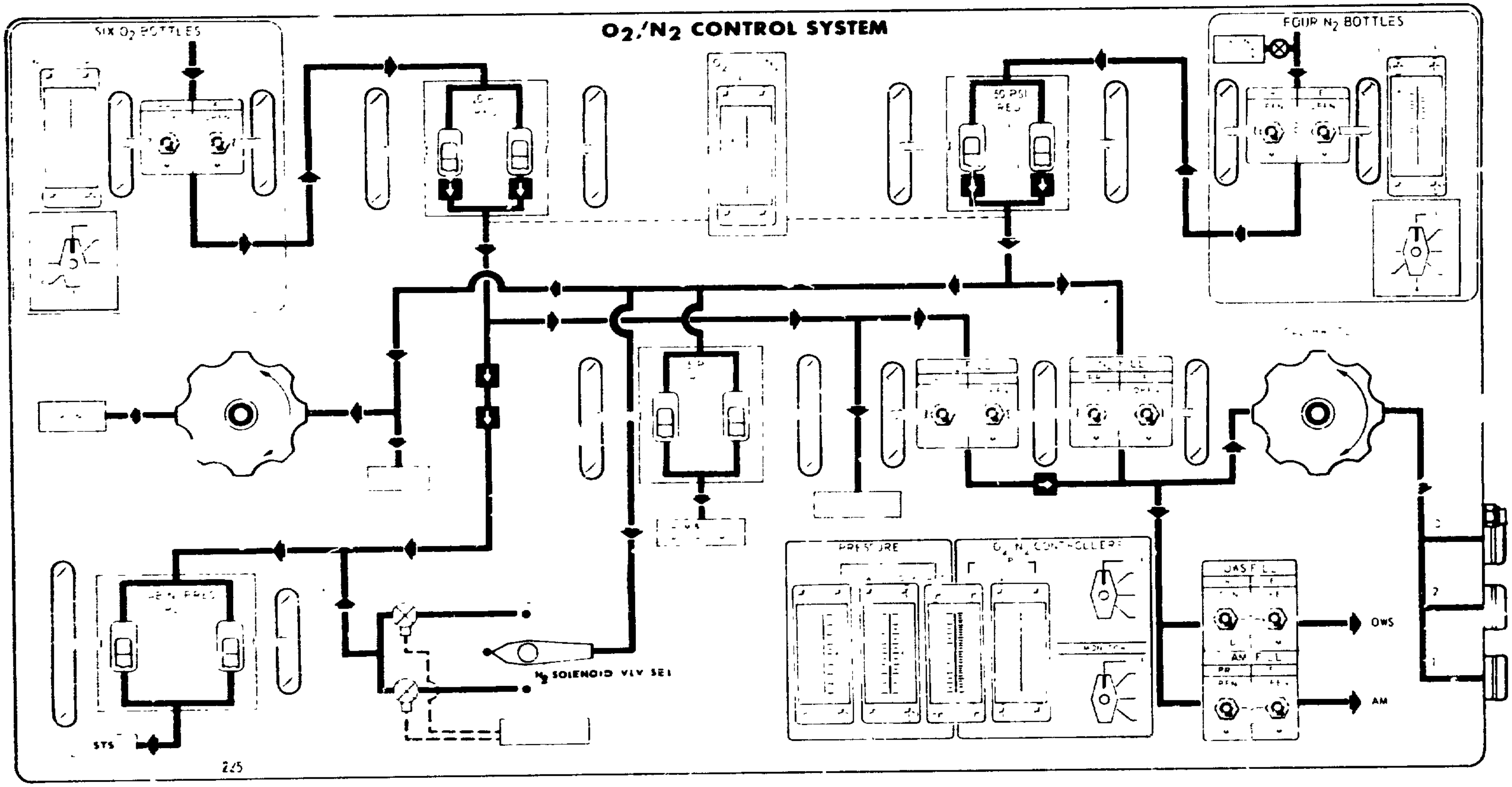
AM 219

UTILITY POWER OUTLET 3 AND MOL SIEVE B BED CYCLE N_2 SUPPLY VALVE

AM 223

SYSTEM 1 LCG RESERVOIR PRESS VALVE (TYPICAL FOR PANEL 224)

PANELS 216, 217, 218, 219, 220, 221, 223, AND 224

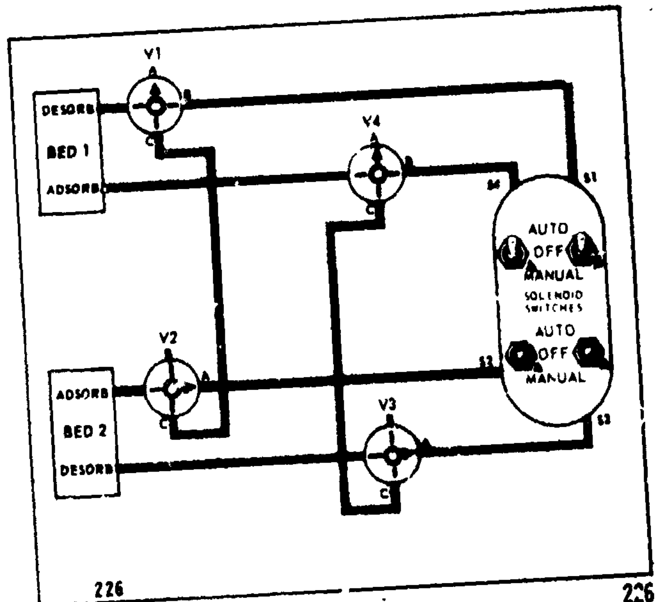


AM

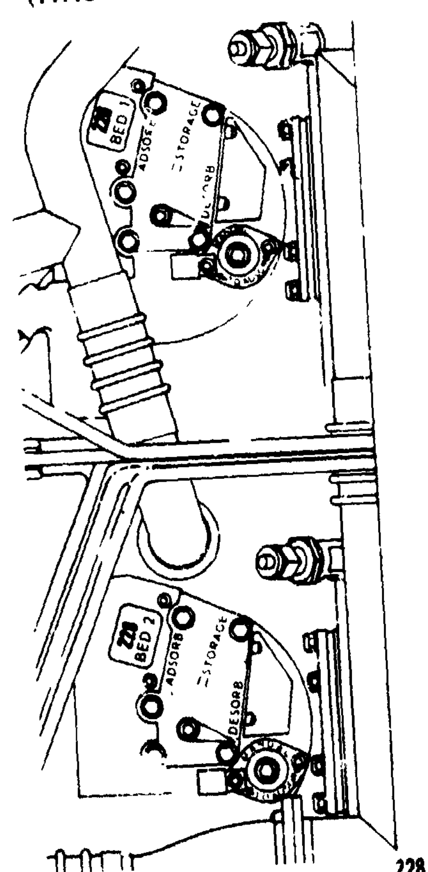
O_2/N_2 CONTROL SYSTEM

225

PANEL 225

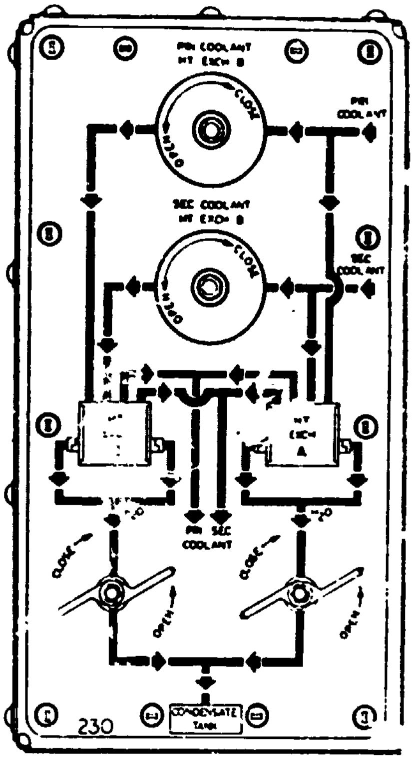


MOLECULAR SIEVE A VALVE CONTROL
(TYPICAL FOR PANEL 227)



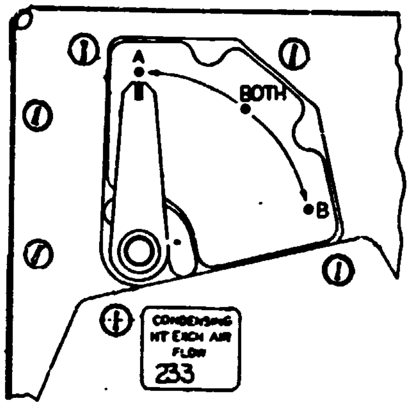
MOLECULAR SIEVE A ABSORB/DESORB VALVE
(TYPICAL FOR PANEL 229)

PANELS 226, 227, 228, AND 229



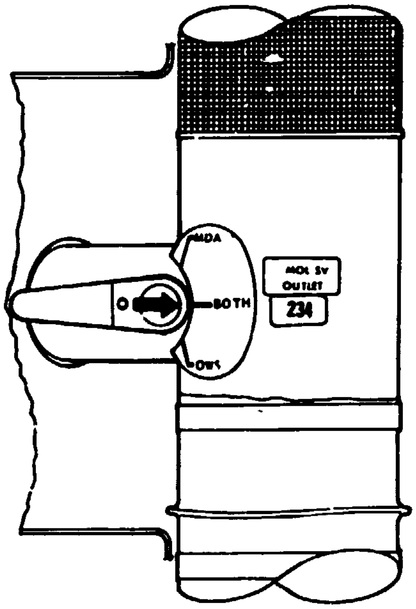
AM 230

MOLECULAR SIEVE A
HEAT EXCHANGER VALVES
(TYPICAL FOR PANEL 232)



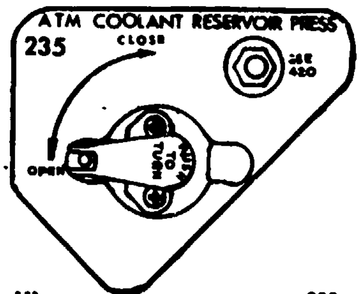
AM 233

MOLECULAR SIEVE A
AIR FLOW VALVE
(TYPICAL FOR PANEL 239)



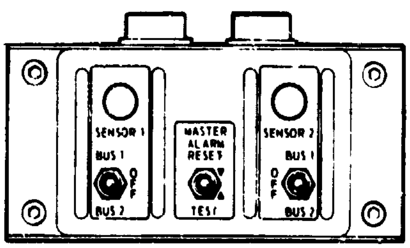
AM 234

MDA/OWS AIR SELECTOR VALVE



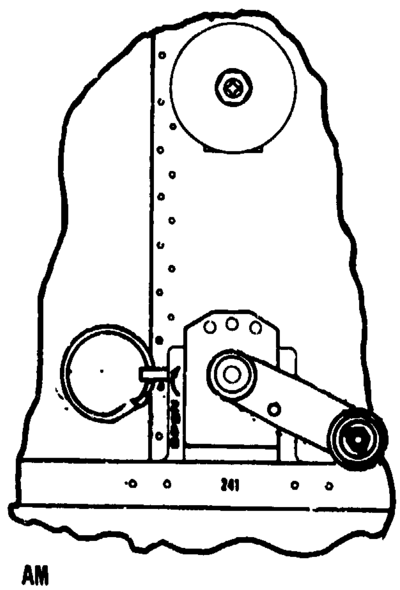
AM 235

ATM COOLANT RESERVOIR
PRESSURE VALVE



AM

FIRE DETECTION CONTROL PANEL
(TYPICAL FOR PANELS
236, 237, 238, AND 392)

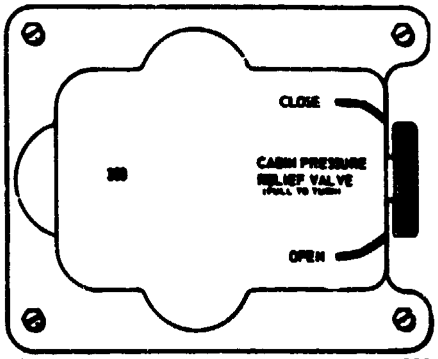


AM

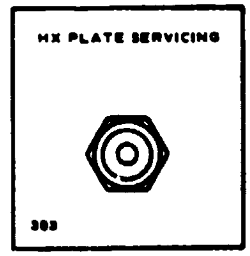
STS WINDOW CRANK
(TYPICAL FOR PANELS
-Z 241, -Y 242,
+Z 243, AND +Y 244)

PANELS 230, 232, 233, 234, 235, 236, 237, 238, 239, 241, 242, 243, 244 AND 392

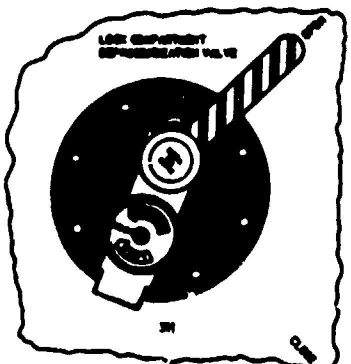
C-6



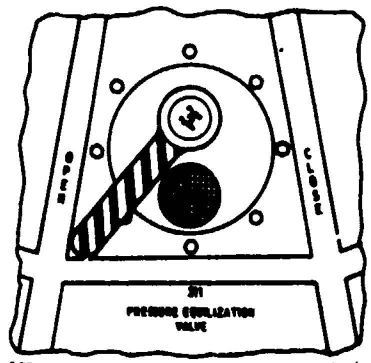
AM 300
FORWARD COMPARTMENT PRESSURE RELIEF VALVE
(TYPICAL FOR PANEL 313 AND 391)



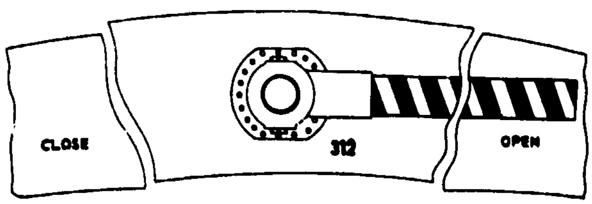
AM 303
HX PLATE SERVICING



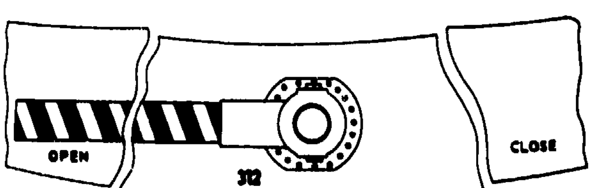
AM 311
FORWARD HATCH PRESSURE
EQUALIZATION VALVE
(TYPICAL FOR PANELS 318 AND 325)



AM FORWARD HATCH PRESSURE 311
EQUALIZATION VALVE
(TYPICAL FOR PANEL 325)



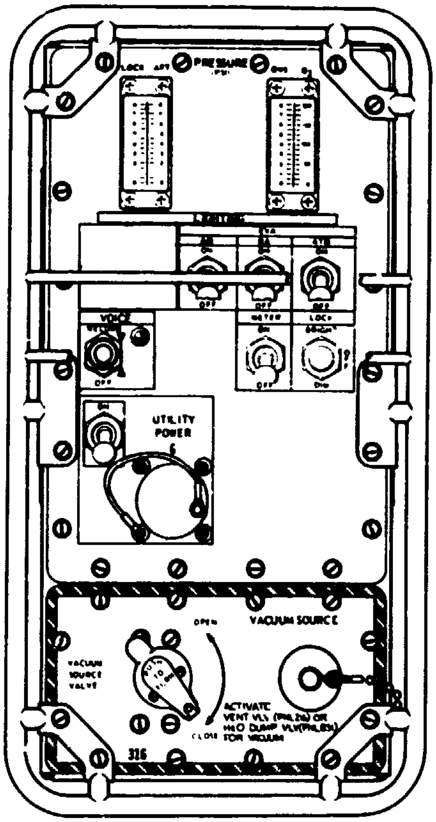
AM FORWARD HATCH HANDLE 312



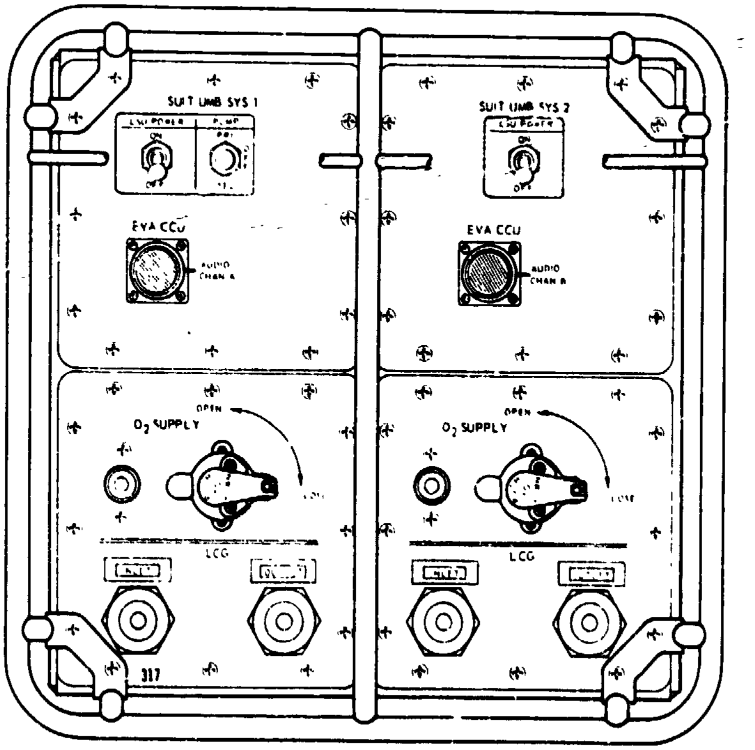
AM FORWARD HATCH HANDLE 312

(TYPICAL FOR PANEL 326)

PANELS 300, 303, 311, 312, 313, 318, 325, 326, AND 391

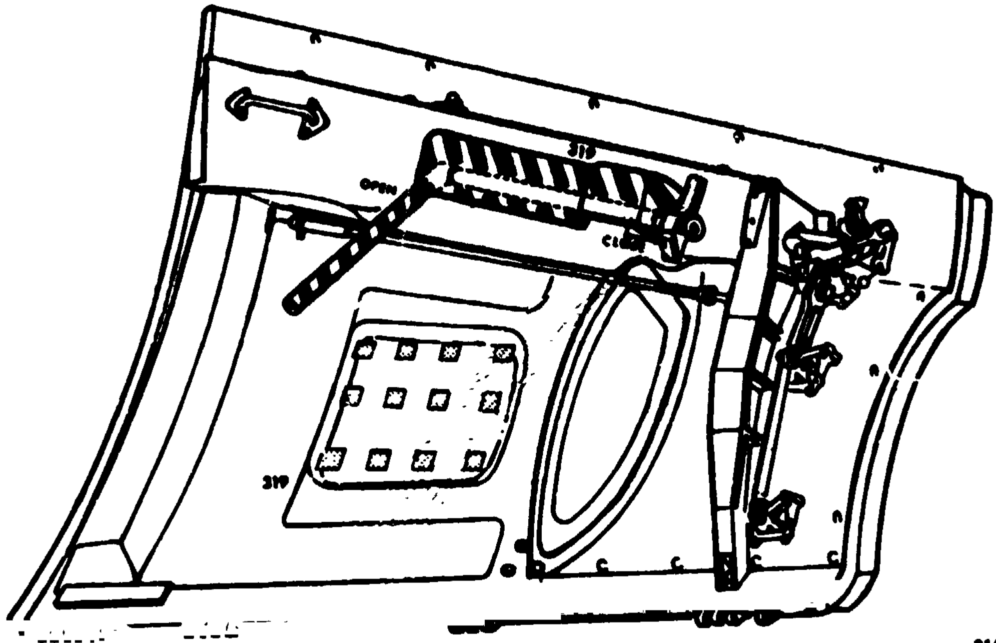


AM EVA SUPPORT CONTROL PANEL 316

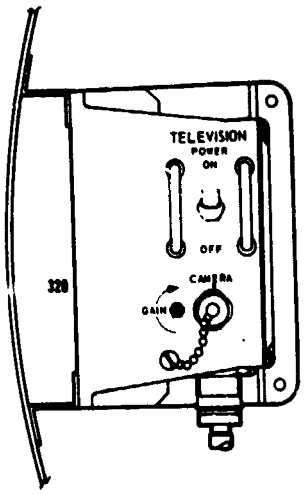


AM EVA I SUIT UMBILICAL CONTROL PANEL 317

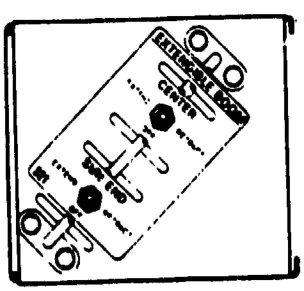
PANELS 316 AND 317



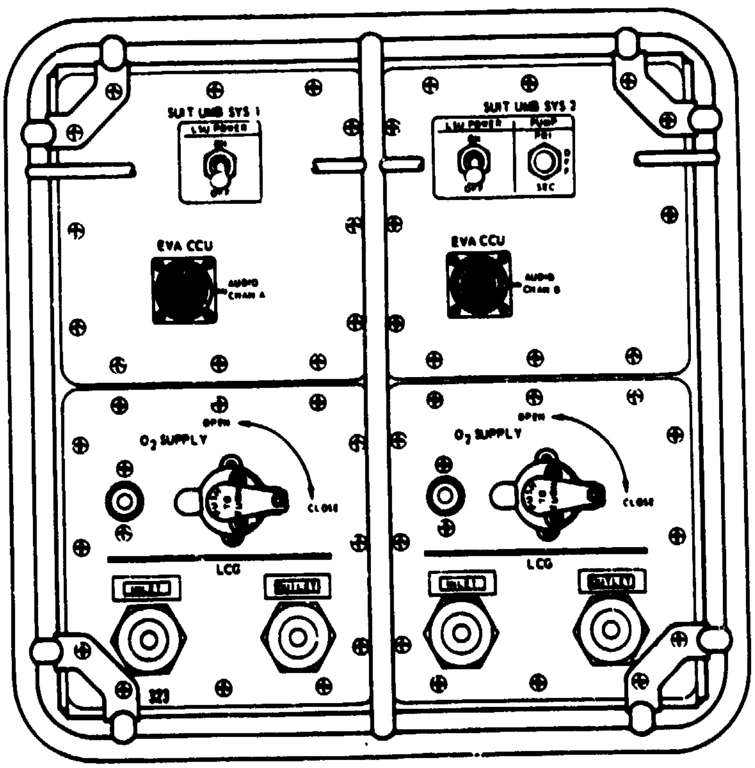
AM EVA HATCH 319



AM TV STATION 320

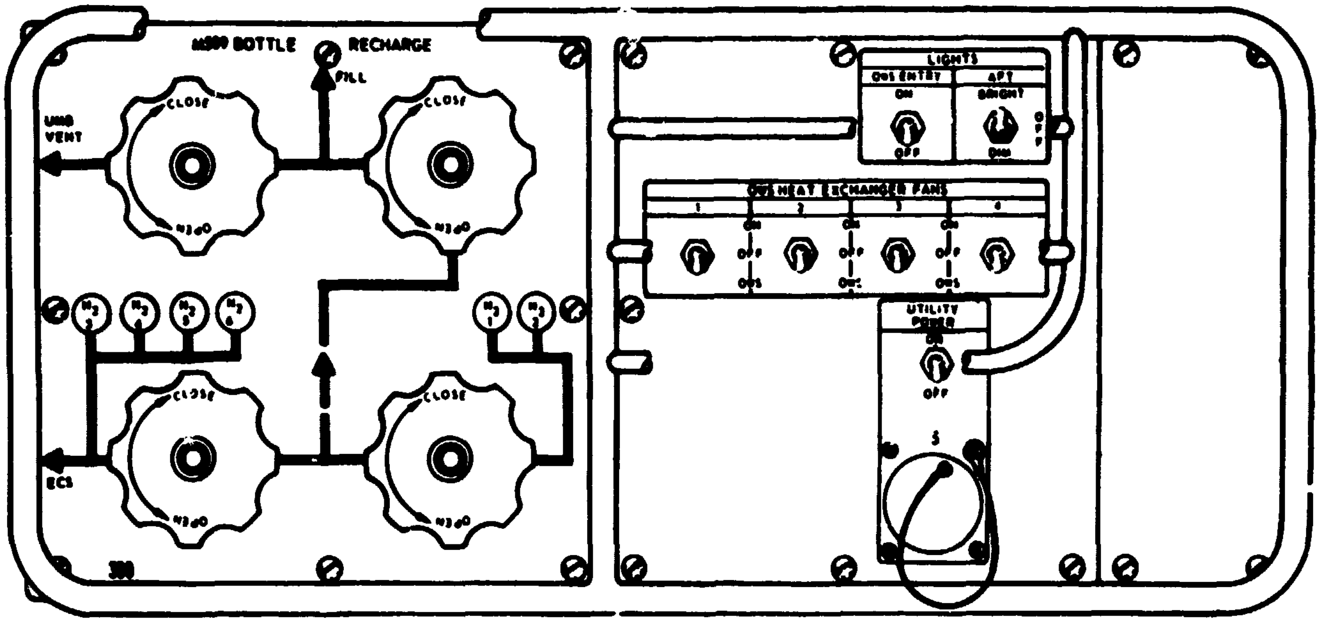


AM EXTENDIBLE BOOM CONTROL PANEL 321

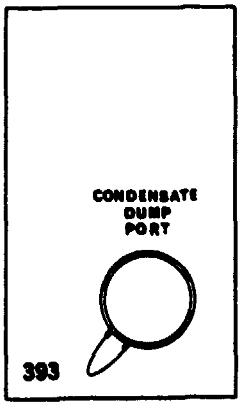


AM EVA 2 SUIT UMBILICAL SYSTEM CONTROL PANEL 323

PANELS 319, 320, 321, AND 323



AM OWS, LTG, TCS CONTROL PANEL 390



AM CONDENSATE DUMP PORT 393

PANELS 390 AND 393

APPENDIX B

MATRIX OF TESTING REQUIRED TO QUALIFY AIRLOCK EQUIPMENT

TESTING REQUIRED TO QUALIFY AIRLOCK EQUIPMENT

STRUCTURES SYSTEM
I = IN-HOUSE
V = VENDOR
■ See Para. 2.1.2 in F767
* Ref: TR 061-052.02.01

ITEM NO.	PART NUMBER	NOMENCLATURE	CRITICALITY	HIGH TEMPERATURE	LOW TEMPERATURE	VIBRATION	SHOCK	TEMP/ALTITUDE	ACCELERATION	EMI	HUMIDITY	O_2 ATMOSPHERE	PRESSURE	BURST PRESSURE	LEAKAGE	LIFE/CYCLE	TEMP CONTROL	ACOUSTIC	STRUCTURAL	FUNGUS	SALT FOG	ENDURANCE	CORROSION	FLUID COMPATIBILITY	VACUUM	HEAT REJECTION	RAPID DECOMPRESSION	TEMP SHOCK	PERFORMANCE	POWER/ALTITUDE	FOGGING	TEST SUPPORT
1	61T101000-1	Static Test Article *	1																*													
2	61A290101-5	Tunnel Extension	1										I		I	I																
3	61A310120-1	STS Window Assy	1	I	I	I		I					I	I		I			I													
4	61A350005-1	Internal Hatch Assy	2	I	I								I			I													I			
5	61A350001-1	Internal Hatch Mech Assy																														
6	61A350102-1	Internal Hatch Window Assy	2	I	I	I		I					I	I		I			I													
7	61A840002-95	Antenna Boom Assy	3																I										I			
8	61A820030-315	Battery Module	2			I																										
9	61C840000-13	Rotary Joint	3	I	I	I					I					I					I								I			
10	61C840001-1	Actuator	3			V																							V			
11	61A310165-1	STS Window Cover	3			I		I								I																
12	61A310170-3	STS Window Cover Mech																														
13	61A310223-1	MDA Radiator	2			I								I																		
		Dynamic Test Articles	1			■												■														
14	61T101000-303	Airlock																														
15	61T101000-1	ATM Deployment Assy																														
16	61T101002-1	Fixed Airlock Shroud																														
17	1D157000-1	Payload Shroud																														
		Deployment Assy Reel	2			V		V		V	V					V		■											V			
18	61B330003-1	Reel Assy																														
19	61B330003-5	Cable Assy																														
		DA Rotary Joint	2	I	I											I													I			
20	61A330032-1	Spring Assembly																														
21	61A330054-1	Lower Truss Trunion Fitting																														
22	61A330066-1	Upper Truss Trunion Fitting																														
23	61A330102-3	Plate																														
24	61A330105-11	Washers																														
25	61A330106-3	Spacer																														
26	61A330119-3	Trunnion Bolt																														
27	61A330134-3	Roller																														
28	61A330135-3	Shoulder Bolt																														

TESTING REQUIRED TO QUALIFY AIRLOCK EQUIPMENT

STRUCTURES SYSTEM (CONTINUED)
I = IN-HOUSE
V = VENDOR
M = ECS/TCS MODULE TEST (ET-1)

ITEM NO.	PART NUMBER	NOMENCLATURE	ENVIRONMENTAL TESTING																													
			CRITICALITY	HIGH TEMPERATURE	LOW TEMPERATURE	VIBRATION	SHOCK	TEMP/ALTITUDE	ACCELERATION	EMI	HUMIDITY	O_2 ATMOSPHERE	PRESSURE	BURST PRESSURE	LEAKAGE	LIFE/CYCLE	TEMP CONTROL	ACOUSTIC	STRUCTURAL	FUNGUS	SALT FOG	ENDURANCE	CORROSION	FLUID COMPATIBILITY	VACUUM	HEAT REJECTION	RAPID DECOMPRESSION	TEMP SHOCK	PERFORMANCE	POWER/ALTITUDE	FOGGING	TEST SUPPORT
29	BLFR-22	Bearing																														
30	VE10686-22	Nut																														
		DA Release Mech	2			I		I							I														I			
31	61C330002-3	DA Deploy Retractor Pin																														
32	61C330002-7	DA Deploy Retractor Pin Cart																														
		DA Latch Mechanism	2	I	I	I										I			I										I			
33	61A330033-1	Latch Mechanism																														
34	61A330067-1	Upper Truss Latch Fitting																														
35	61A330094-3	Bushing																														
36	61A310136-3	Roller																														
37	61A310137-3	Bracket																														
38	61A310137-5	Bracket																														
39	61A310150-3	Bushing																														
40	52-79705-43	Switch Assembly																														
		ATM Rigidizing Mech Subsys	2	I	I	I					I					I			I										I			
41	61A330040-3	Rigidizing Mechanism																														
42	61A330068-7	Corner Housing Ftg Assy																														
43	61A330069-3	Cam Receptacle Ftg																														
44	61A290101-7	Tunnel Ext w/Seal Coating	1			I							I		I				I													
45	61A310120-303	STS Window Assy	1										I																		I	
46	61A350126-5	Seal	2	I	I										I																	
47	61A800091-83	Stowage Cabinet	3			I																										
48	61A300055-159	Stowage Cabinet	3			I																										
49	61A810083-79	Meter Mount Assembly	3			I																										
50	61T101000-1	DA Gen Assy (STA 3)	2																										V			
51	61B820001	EVA Boom	3	V	V	V				V	V					V									V				V			

TESTING REQUIRED TO QUALIFY AIRLOCK EQUIPMENT

ENVIRONMENTAL CONTROL SYSTEM (ECS)

I = IN-HOUSE
V = VENDOR
M = ECS/TCS MODULE TEST (ET-1)
* = VENDOR & PRE-ET-1 IN-HOUSE

ITEM NO.	PART NUMBER	NOMENCLATURE	ENVIRONMENTAL TESTING																													
			CRITICALITY	HIGH TEMPERATURE	LOW TEMPERATURE	VIBRATION	SHOCK	TEMP/ALTITUDE	ACCELERATION	EMI	HUMIDITY	O_2 ATMOSPHERE	PRESSURE	BURST PRESSURE	LEAKAGE	LIFE/CYCLE	TEMP CONTROL	ACOUSTIC	STRUCTURAL	FUNGUS	SALT FOG	ENDURANCE	CORROSION	FLUID COMPATIBILITY	VACUUM	HEAT REJECTION	RAPID DECOMPRESSION	TEMP SHOCK	PERFORMANCE	POWER/ALTITUDE	FOGGING	TEST SUPPORT
1	52-83700-245	Selector Valve	2													I						M	M									
2	52-83700-419	Mole Sieve	2			I												I				M										
3	52-83700-491	Temp Control Valve	2													I									M							
4	52-83700-729	Radiator Bypass Valve	2													I						M			M							
5	52-83700-833	Coolant Pump	2			M										I						M			M							
6	52-83700-1223	Heat Exch & H2O Separator	2			V										I						M	M									
7	52-83700-1227	Cabin Heat Exch	2			V																M	M									
8	52-83700-1203	Manual S/O Valve	2													I						M	M									
9	52-83700-1205	Gnd Cooling Heat Exch	2			V								V											M							
10	52-83700-1207	Regenerative Heat Exch	2			V								V											M							
11	52-83700-1209	Repressure Valve	2			I							I	I		I																
12	52-83700-1211	Water Tank	2						I							I						M	M									
13	52-83708-127	Water Nipple	2	V	V	V						V	V	V	V	I																
14	61A830174-13	EVA/IVA Disconnect	2	V	V	V						V	V	I		I							M									
15	52-83771-13	Cooling System Filter	2																			M			M							
16	61B830014-1	Pressure Equal Valve	2	V	V	V	V	V			V	V	V	V		V			V		V				V							
17	61B830010-305,-313	Molecular Sieve	2	V	V	V		V	V	V	V	V	V	V		V					V	V			V	V						
18	61B830011-1	Water Relief Valve	2	V	V	V		V	V		V	V	V	V		V					V	M	M									
19	61B830012-1	Vacuum Isolation Valve	2		V	V		V			V	V		V		V					V	M	M		M							
20	61C830060-3	Water Check Valve	2			I								I		I						M	M	I								
21	61C830064-1	Hi Press S/O Valve (3/8")	2			*		V	V		V	V		V								M	M	M								
22	61C830065-1	Manual Inflator	3	I										I		I									I							
23	61C830069-303,-305	Water Pump	2			V				V				V		V						M	M	M								
24	52-83700-1213	Press Relief Valve, Cabin	2	V	V	V					V					M						M	M		M							
25	61A830189-301,-303	Thermal Capacitor	2	I	I	I		I					I	I			I															
26	61C830083-9	120 psig Reg	2		V	V			V			V	V	V	V	V						M	M									
27	61C830085-1	Check Valve	2	V								V		V											V							
28	61C830086-1	Solenoid Valve	2			V		V	V	V	V	V	V	V		V						M	M									
29	61C830068-1	Condensate Hose	2	V	V	V			V			V	V	M	V	V							M	M								
30	61C830068-3	Coolant Hose	2	V	V	V			V			V	V	M	V	V						M			M							
31	61C830068-27	ATM Pump Hose	2											M									M	M	M							
32	61C830068-11	Suit Cooling Hose	2											M									M	M	M							

TESTING REQUIRED TO QUALIFY AIRLOCK EQUIPMENT

ECS (CONTINUED)
I = IN-HOUSE
V = VENDOR
M = ECS/TCS MODULE TEST (ET-1)

			ENVIRONMENTAL TESTING																													
ITEM NO.	PART NUMBER	NOMENCLATURE	CRITICALITY	HIGH TEMPERATURE	LOW TEMPERATURE	VIBRATION	SHOCK	TEMP/ALTITUDE	ACCELERATION	EMI	HUMIDITY	O_2 ATMOSPHERE	PRESSURE	BURST PRESSURE	LEAKAGE	LIFE/CYCLE	TEMP CONTROL	ACOUSTIC	STRUCTURAL	FUNGUS	SALT FOG	ENDURANCE	CORROSION	FLUID COMPATIBILITY	VACUUM	HEAT REJECTION	RAPID DECOMPRESSION	TEMP SHOCK	PERFORMANCE	POWER/ALTITUDE	FOGGING	TEST SUPPORT
33	61C830081-1	Metering Valve	2	V	V	V			V		V		V	V	V						V											
34	52-83708-123	Water Nipple	2	V	V	V						V	V	V	V	V						M	M									
35	52-83708-125	Water Coupler	2	V	V	V						V	V	V	V	V						M	M									
36	52-83708-129	Water Coupler	2	V	V	V						V	V	V	V	I						M	M									
37	61B830019-3	02 Controller	3	V	V	V	V	V	V	V	V		V			V						M	M			V						
38	61C830093-3	Cabin Press Regulator	2	V	V	V			V		V	V	V	V	V	V					V	M	M									
39	61B830017-3	3-Way Valve	2	V	V	V			V		V	V		V		V			V		V	M	M		V							
40	61C830083-7, -11	150 psig N2 Press Reg Pkg	2	V	V	V			V				V	V	V	V						M	M									
41	61B830024-3	02 Storage Tank	2	V	V	V			V				V	V		V						V										
42	61C830090-1	N2 Storage Tank	2	V	V								V	V		V						V										
43	61B830016-7	02 Fill Valve Assy	2	V	V	V		V	V	V	V			V		V			V		V	V			V							
44	61C830080-3	Regulator 5 psi	2	V	V	V		V	V			V		V		V					V	M	M									
45	61B830015-5	Circulation Valve	2	V	V	V				V	V	V		V		V			V		V	M	M						V			
46	61A830035-1	H20 Dump Heater Assy	2			I																										
47	61C830088-1	Duct Assy	2			I							I	I	I	I																
48	61A830205-11	Duct Assy	2			I							I	I	I	I																
49	61C830089-1	Duct Elbow	2	V	V	V			V		V	V		V																		
50	52-83700-421	Reservoir Tank	2											I		I						M			M							
51	52-83700-461	02 Heat Exchanger	2			I																M			M							
52	52-83713-31	Manual S/O Valve	2		I																	M			M							
53	52-83708-159	Oxygen Press Cap	2	V	V	V						V		M	V	V							M									
54	61C830066-1	Water Filter	2	V		V							V	V								M	M	V								
55	52-83708-151	Water Nipple	2																			M	M									
56	61C830068-9	H20 Hose	2	V	V	V			V			V	V	V		V																
57	61C830094-1	H20 S/O Valve	2	V	V	V		V						V		V						M			M							
58	52-83700-755	Check Valve	2																			M										
59	52-83708-139, -141	Quick Disconnects	2	V	V	V						V		V		V																
60	52-83708-171	Coupler Assy	2													V																
61	52-83708-173	Nipple QD																														
62	52-83708-175	Flange QD																														
63	52-83708-177	Pin QD																														
64	52-83712-7	Spring Assy	3													V			V													

TESTING REQUIRED TO QUALIFY
AIRLOCK EQUIPMENT

ECS (CONTINUED)
I = IN-HOUSE
V = VENDOR
M = ECS/TCS MODULE TEST (ET-1)

ITEM NO.	PART NUMBER	NOMENCLATURE	CRITICALITY	HIGH TEMPERATURE	LOW TEMPERATURE	VIBRATION	SHOCK	TEMP/ALTITUDE	ACCELERATION	EMI	HUMIDITY	O_2 ATMOSPHERE	PRESSURE	BURST PRESSURE	LEAKAGE	LIFE/CYCLE	TEMP CONTROL	ACOUSTIC	STRUCTURAL	FUNGUS	SALT FOG	ENDURANCE	CORROSION	FLUID COMPATIBILITY	VACUUM	HEAT REJECTION	RAPID DECOMPRESSION	TEMP SHOCK	PERFORMANCE	POWER/ALTITUDE	FOGGING	TEST SUPPORT
65	61A830035-13	H2O Dump Heater Assy	3													M																
66	61A830155-1	Coldplate	2			I							I	I																		
67	61A830217-1	Coldplate	2			I							I	I																		
68	61A830377-1	Thermal Capacitor	2	I	I	I								I		I	I		I													
69	61B830010-5	Mole Sieve Adsorber	2	V							V					V																
70	61B830010-7	Mole Sieve Valve	2	V							V					V																
71	61B830010-11	Mole Sieve Valve	2	V							V					V																
72	61B830010-65	Mole Sieve Timer	2	V							V					V																
73	61B830010-67	Mole Sieve Controller	2	V							V					V																
74	61B830019-5	Coolant Controller	2			V		V								V																
75	61B830026-1	Latching Solenoid	2	V	V	V		V	V	V				V		V									V							
76	61B830027-1	Filter Assy	2	V	V	V			V		V			V		V						V			V							
77	61B830028-1	Controller Flow Assy O2	2	V	V	V					V		V	V		V																
78	61B830029-3	3-Way Solenoid Valve	2	V	V	V		V			V		V	V	V	V									V							
79	61B830030-3	Relief Valve	2	V	V	V					V			V		V									V							
80	61B830031-7	Volume Compensator	2	V	V	V		V			V			V		V																
81	61C830064-5	Coolant S/O Valve																				M	M	M								
82	61C830064-7	N2 Hi Press S/O Valve	2			I										I																
83	61C830064-9	Shutoff Coolant Valve	2	V	V											V																
84	61C830064-11, -13, -15, -19	O2 Hi Press S/O Valve	2													V																
85	61C830064-17	N2 Hi Press S/O Valve	2													V																
86	61C830064-21	N2 Hi Press S/O Valve	2	V	V	V										V																
87	61C830064-23	Hi Press S/O Valve	2	V	V	V								V	V	V																
88	61C830068-11, -143, -195, -417, -437	Flex Hose	2											I	I	I																
89	61C830068-91, -103, -207, -209, -221, -227, -229, -263, -419, -421, & 90684 (Equiv to 61C830068-755)	Flex Hose	2			I								I	I	I																

TESTING REQUIRED TO QUALIFY AIRLOCK EQUIPMENT

ECS (CONTINUED)

I = IN-HOUSE
V = VENDOR
M = ECS/TCS MODULE TEST (ET-1)

ITEM NO.	PART NUMBER	NOMENCLATURE	ENVIRONMENTAL TESTING																													
			CRITICALITY	HIGH TEMPERATURE	LOW TEMPERATURE	VIBRATION	SHOCK	TEMP/ALTITUDE	ACCELERATION	EMI	HUMIDITY	O_2 ATMOSPHERE	PRESSURE	BURST PRESSURE	LEAKAGE	LIFE/CYCLE	TEMP CONTROL	ACOUSTIC	STRUCTURAL	FUNGUS	SALT FOG	ENDURANCE	CORROSION	FLUID COMPATIBILITY	VACUUM	HEAT REJECTION	RAPID DECOMPRESSION	TEMP SHOCK	PERFORMANCE	POWER/ALTITUDE	FOGGING	TEST SUPPORT
90	61C830068-101, -107	Hose Assy's	2			V							V	V		V																
	-247, -405																															
91	61C830068-105, -159,	Flex Hose	2			I																										
	-261, -289																															
92	61C830068-755	N_2 Recharge Hose	2			V							V	V	V	V																
93	61C830068-255	N_2 Recharge Flex Hose	2	V	V	V								V		V						V										
94	61C830081-3	Metering Valve	2																			M			M							
95	61C830083-13	N_2 Press Regulator	2		V	V										V																
96	61C830085-3	Check Valve	2	V	V	V		V								V						M	M		V							
97	61C830085-5	Check Valve	2			V																										
98	61C830085-9	Condensate Check Valve	2			V										V																
99	61C830086-3	Condensate Solenoid Valve	2			V				V	V		V	V		V						M	M		M							
100	61C830094-7	H_2O S/O Valve	2			V																										
101	61C830095-1	GO_2 Valve	2	V	V	V			V		V			V		V						M	M									
102	61C830096-9, -11	Temp Control Valve 47°F	2	V	V	V			V					V		V	V								V							
103	61C830097-5	H_2O Servicing Hose	3	V	V	V								V																		
104	61C830097-7	H_2O Jumper Hose	3	V	V	V								V																		
105	61C830098-1	QD Coupler(Rechg Sta)	3	V	V	V							V	V	V	V																
106	61C830098-3	QD Nipple Blind (Rechg Sta)	3	V	V	V							V	V	V	V																
107	61C830098-5	QD Nipple Live (Rechg Sta)	3	V	V	V							V	V	V	V																
108	61C830100-3	Bleed Valve	2	V	V	V		V			V			V	V	V									V							
109	1B79636-549	QD Nipple	2			I																										
110	61A830125-1	Comp Pwr Supply Coldplate	2																													M
111	61A830183-1	Comp Pwr Supply Coldplate	2																													M
112	61C830070-3	Orifice	2																													M
113	52-83700-1201	Vent Valve	2																													M
114	5K206004	PLV Fan (GFE)	2																													M
115	2000-5	Shut Off Valve	3										I	[illegible]	I	I			I													
116	61A830412-61	Saddle Valve	2	I	I									I	I	I									I				I			
117	61A830416-1	3 Ft. Servicing Hose	2	I	I									I	I	I													I			
118	61C830102-1	Water Pump (CSM)	2			I				I						I													I			
119	20M33242-[illegible]	GFE Saddle Valve	2	I	I									I	I	I									I				I			

TESTING REQUIRED TO QUALIFY AIRLOCK EQUIPMENT

ELECTRICAL POWER SYSTEM AND SEQUENTIAL SYSTEM

I = IN-HOUSE
V = VENDOR
M = ECS/TCS MODULE TEST (ET-1)

ITEM NO.	PART NUMBER	NOMENCLATURE	ENVIRONMENTAL TESTING: CRITICALITY	HIGH TEMPERATURE	LOW TEMPERATURE	VIBRATION	SHOCK	TEMP/ALTITUDE	ACCELERATION	EMI	HUMIDITY	O_2 ATMOSPHERE	PRESSURE	BURST PRESSURE	LEAKAGE	LIFE/CYCLE	TEMP CONTROL	ACOUSTIC	STRUCTURAL	FUNGUS	SALT FOG	ENDURANCE	CORROSION	FLUID COMPATIBILITY	VACUUM	HEAT REJECTION	RAPID DECOMPRESSION	TEMP SHOCK	PERFORMANCE	POWER/ALTITUDE	FOGGING	TEST SUPPORT
1	52-79705-23	Toggle Switch	2									I																				
2	52-79713-13	Relay	2	V	V	V		V	V	V			V			V													V			
3	52-79721-310	Circuit Breaker	2		V			V								V																
4	52-79721-322	Circuit Breaker	2									I																				
5	61B769004-9	NICAD Battery	2	V	V	V		V	V					V		V												V	V			
6	61B769005-7	Voltage Regulator	2	V		V		V		V	V					V																
7	61B769006-9	Battery Charger	2	V		V		V		V	V					V																
8	61B7C9008-17	Voltage Adj Pot	3	V	V	V		V			V	V				V				V								V	V			
9	61B769008-19	Voltage Adj Pot	3	V	V	V		V				V				V												V	V			
10	61C769007-1	Indicator Light	3		V	V		V	V			V	V			V													V			
11	61C769007-3	Indicator Light	3		V	V		V	V			V	V			V													V			
12	61C769007-5	Indicator Light	3		V	V		V	V			V	V			V													V			
13	52-79720-322	Fuse	3		I	I		I																								
14	52-79717-1, -11, -13	Shunt	3					V																								
15	61T060056-13	Diode Panel	3		I	I		I																								
16	61T060055-1	Relay Panel (Foam Config)	2		I	I		I																								
17	52-79715-11	Relay (SDO)	2	V	V	V										V														V		
18	61C769011-5, -9	Thermostat	2													V														V		
19	61B769012-1, -3	Current Sensor	3		V	V		V		V	V					V																
20	61B769013-3, -13	Electrical Heater Rod	2		V	V		V			V					V														V		
	-15, -17																															
21	61B769010-1, -3	Power Relay	3		V	V		V								V														V		
22	52-79720-31	Fusistor	3			I																										
23	52-79721-312	Circuit Breaker	2		V			V																								
24	61A762221-73	Filter Panel	2		I	I		I																								
25	61A762296-23, -31	Zero-G Connector Dust Cover	3			I					I																					
26	61A800026-9	Fire Detector Control Panel	3	I	I	I	I						I																			
27	61A820045-5	Lamp Holder Assy	3			I		I								I																
28	52-79730-27	Light Assy																														
29	52-79730-23	Green Lens																														
30	61A820105-307	Directional Lamp Assy	3	I	I	I																							I			
31	61B769004-13	NICAD Battery	2			V			V					V		V													V			

TESTING REQUIRED TO QUALIFY AIRLOCK EQUIPMENT

EPS AND SEQUENTIAL SYSTEM (CONTINUED)

I = IN-HOUSE
V = VENDOR
M = ECS/TCS MODULE TEST (ET-1)

ITEM NO.	PART NUMBER	NOMENCLATURE	CRITICALITY	HIGH TEMPERATURE	LOW TEMPERATURE	VIBRATION	SHOCK	TEMP/ALTITUDE	ACCELERATION	EMI	HUMIDITY	O_2 ATMOSPHERE	PRESSURE	BURST PRESSURE	LEAKAGE	LIFE/CYCLE	TEMP CONTROL	ACOUSTIC	STRUCTURAL	FUNGUS	SALT FOG	ENDURANCE	CORROSION	FLUID COMPATIBILITY	VACUUM	HEAT REJECTION	RAPID DECOMPRESSION	TEMP SHOCK	PERFORMANCE	POWER/ALTITUDE	FOGGING	TEST SUPPORT
32	61B769008-21	Voltage Adj Pot	3	V	V	V		V				V				V												V	V			
33	61C769014-1, -3	Toggle Switch	2		V	V		V	V		V	V	V			V																
34	61C769015-1	Relay	2			V				V																						
35	61C769016-1, -3	Relay	2							V						V																
36	61C769018-1	Silicon Controlled Rectifier	2	I	I	I		I								I																
37	61A762358-1	Circuit Breaker Panel	2			I										I																
38	52-79703-79	Relay	2																													M

TESTING REQUIRED TO QUALIFY
AIRLOCK EQUIPMENT

INSTRUMENTATION SYSTEM

I = IN-HOUSE
V = VENDOR
M = ECS/TCS MODULE TEST (ET-1)

ITEM NO.	PART NUMBER	NOMENCLATURE	ENVIRONMENTAL TESTING																												
			CRITICALITY	HIGH TEMPERATURE	LOW TEMPERATURE	VIBRATION	SHOCK	TEMP/ALTITUDE	ACCELERATION	EMI	HUMIDITY	O_2 ATMOSPHERE	PRESSURE	BURST PRESSURE	LEAKAGE	LIFE/CYCLE	TEMP CONTROL	ACOUSTIC	STRUCTURAL	FUNGUS	SALT FOG	ENDURANCE	CORROSION	FLUID COMPATIBILITY	VACUUM	HEAT REJECTION	RAPID DECOMPRESSION	TEMP SHOCK	PERFORMANCE	POWER/ALTITUDE	FOGGING	TEST SUPPORT
1	52-85713-809	Interface Package	2	V	V	V		V	V	V	V																					
2	52-85713-871	Tape Recorder	3	I	I				I				I												I							
3	61A880051-5	DC Voltage Monitor	3			I																										
4	61A880051-11	Voltage Sensor	3			I																										
5	61A880061-3, -13	DC MV Monitor	3			I																										
6	61A880063-1	Tape Monitor	3			I																										
7	61B880051-15	Portable Timer	3	I	I	I		I	I	I	I	I				I																
8	52-88715-49, -123	PPCO2 Detector	2			V			V							I																
9	61A880051-15	DC Voltage Monitor	3			I																										
10	61A880063-7, -19, -37	Level Detector	3			I																										
11	61A880063-5	Dual Bus Monitor	3			I																										
12	61A880064-3	Attenuator	3			I																										
13	61B880053-3	Flow Meter	3	V	V	V		V		V	V											M										
14	61B880054-3	Humidity Sen Elec Pkg	3		V	V		V	V													M										
15	61B880055-1	PPO2 Sensor	1		V	V		V	V	V	M	V	V			I						M										
16	52-88715-43, -117	CO2 Detector	2													I						M										
17	61A880061-9	AGC Monitor	3			I																										
18	61A880061-11	Battery Current Monitor	3			I																										
19	61C880051-1	DC-DC Converter	2	V	V	V		V	V	V																			V			
20	61B880056-5	Low Range Press Transducer	3	V	V	V		V	V	V	V	V	V	V		V																
21	61C880052-1	DC-DC Converter Meter Panel	2	V	V	V		V	V	V	V					V																
22	61B880058 -31	Gas Flowmeter	3	V	V	V		V	V	V	V	V	V			V																
23	52-85713-843	Tape Recorder	3	V	V	V				V			V			V																
24	52-85713-847	Tape Recorder	3	V	V	V										V																
25	52-85713-893	PCM Programmer	2	V	V			V																								
26	52-857,3-0893	PCM Programmer	2			V																										
27	52-85721-273	Temp Sensor	3			V																						V				
28	52-88705-41, -495, -705	Pressure Transducer	3			V																										
29	52-88705-53	Pressure Transducer	3			V																										
30	52-88705-713	Switch Diff Press	3		V	V		V	V	V	V	V		V		V						M										
31	52-88705-715, -727	Pressure Switch	3		V	V		V								V																

TESTING REQUIRED TO QUALIFY AIRLOCK EQUIPMENT

INSTRUMENTATION SYSTEM (CONTINUED)

I = IN-HOUSE
V = VENDOR
M = ECS/TCS MODULE TEST (ET-1)

			ENVIRONMENTAL TESTING																													
ITEM NO.	PART NUMBER	NOMENCLATURE	CRITICALITY	HIGH TEMPERATURE	LOW TEMPERATURE	VIBRATION	SHOCK	TEMP/ALTITUDE	ACCELERATION	EMI	HUMIDITY	O_2 ATMOSPHERE	PRESSURE	BURST PRESSURE	LEAKAGE	LIFE/CYCLE	TEMP CONTROL	ACOUSTIC	STRUCTURAL	FUNGUS	SALT FOG	ENDURANCE	CORROSION	FLUID COMPATIBILITY	VACUUM	HEAT REJECTION	RAPID DECOMPRESSION	TEMP SHOCK	PERFORMANCE	POWER/ALTITUDE	FOGGING	TEST SUPPORT
32	52-88705-723, -729	Pressure Switch	3		V	V		V						V		V																
33	52-88705-721	Pressure Transducer	3		V	V		V	V		V	V		V		V																
34	52-88705-723	Pressure Switch	3	V	V	V										V																
35	52-88705-725	ΔP Switch	3		V	V		V	V		V	V		V		V																
36	52-88715-67	End Plate	3			I																										
37	52-88715-93, -95	Stowage Assy	3			I																										
38	61A830301-13	Plate Assy Sensor	3			I																										
39	61A880051-33	Range Expander Sig Condit'er	3		I	I		I		I																			I			
40	61A880063-73, -77, -99 thru -115	Level Detectors	3		I	I		I		I																			I			
41	61B880053-5	Flowmeter Converter	3	V	V	V		V	V	V	V		V																			
42	61B880053-11	Flowmeter Converter	3																			M										
43	61B880054-5	Humidity Sensor	3			V			V													M										
44	61B880058-39, -49	Gas Flow Sensor	3			V																										
45	61B880058-45	Gas Flow Sensor Converter	3	V	V	V		V	V	V	V	V	V	V		V																
46	61B880059-7	Press Loss Detector	2	V	V	V		V	V	V	V	V	V	V		V						M										
47	61B880060-1	UV Fire Detector	3	V	V	V	V		V		V	V	V					V				M										
48	61B880060-3	UV Fire Detector	3		V			V		V																						
49	61B830060-5	UV Fire Detector	3			V				V						V																
50	61B880062-3	QCM/CM's Unit	3		V	V			V	V	V			V		V																
51	61B880063-1	Acoustic Noise System	3		V	V		V	V	V	V																					
52	61B880064-1	Vibration Measuring System	3		V	V		V	V	V	V																					
53	52-85713-849	Tape Recorder	3			V										V																
54	61A800026-9	Control Panel	3			I																										

TESTING REQUIRED TO QUALIFY AIRLOCK EQUIPMENT

COMMUNICATIONS SYSTEM

I = IN-HOUSE
V = VENDOR
M = ECS/TCS MODULE TEST (ET-1)

ITEM NO.	PART NUMBER	NOMENCLATURE	CRITICALITY	HIGH TEMPERATURE	LOW TEMPERATURE	VIBRATION	SHOCK	TEMP/ALTITUDE	ACCELERATION	EMI	HUMIDITY	O_2 ATMOSPHERE	PRESSURE	BURST PRESSURE	LEAKAGE	LIFE/CYCLE	TEMP CONTROL	ACOUSTIC	STRUCTURAL	FUNGUS	SALT FOG	ENDURANCE	CORROSION	FLUID COMPATIBILITY	VACUUM	HEAT REJECTION	RAPID DECOMPRESSION	TEMP SHOCK	PERFORMANCE	POWER/ALTITUDE	FOGGING	TEST SUPPORT
1	61A850003-313	Speaker Intercom	3		I	I		I	I	I	I	I				I											I					
2	61B850005-3	CRDU	2		V	V		V	V	V					V	V																
3	61A850004-311	Audio Load Comp	2		I	I		I	I	I	I					I																
4	61B850012-3, -13	Caution and Warning Unit	3		V	V		V	V	V	V				V	V																
5	52-85701-13	Coax Switch	2													I														I		
6	52-85713-367	TM Transmitter	2		I										I	I																
7	52-85714-23	DCS Relay	2													I																
8	52-85722-21	UHF Whip	2			I																										
9	61A840003-9	Discone Antenna	3	I	I	I																								I		
10	61C850001-1	TM Transmitter	2					I								I														I		
11	61C850002-3	Speaker	3		V	V	V	V			V	V				V																
12	61C850003-3	Microphone	3		V	V	V	V			V	V				V																
13	61B850011-5 (EQV)	Case, Digital Clock	3											V																		
14	61A850005-3	Klaxon	3			I																										
15	61C850009-1	Toggle Switch	3													I																
16	61A850007-301	Lamp Dimmer Assy	3		I	I		I	I	I	I	I				I																
17	61B850009-3, -5	Power Inverter Coolant Pump	2		V	V		V	V	V						V						M			M							
18	61B850007-3, -5	Suit Comp Pwr Inverter	2		V	V		V	V	V	V					V					V	M										
19	61A850006-3	Shunt Regulator	3	I	I	I		I		I	I					I																
20	52-85714-27	DCS Receiver	2													I																
21	A05A0027	Electronic Timer	3													I																
	(61B850016-1)																															
22	61B850018-27	Teleprinter	3		V	V		V	V		V	V				V																
23	61B850019-9	Interface Electronic Unit	3		V	V		V	V	V	V					V																
24	65700/AM	Lamp Dimmer Limit Sw.	3													I														I		
25	52-85703-23	Quadriplexer	2																											I		
26	52-85713-67	TM Transmitter	3		I	I	I		I							I																
27	52-85714-31	DCS Receiver	2		V	V		V	V	V	V					V																
28	61A850008-303	Lamp Dimmer Control Unit	3		I	I		I	I	I	I	I				I																
29	61A840083-1	VHF Ranging Helix Ant	3	I	I	I																								I		
30	61A840083-305	VHF Ranging Helix Ant	3			I																										
31	61A840092-1, -7	Stub Antenna	2			I																										

TESTING REQUIRED TO QUALIFY AIRLOCK EQUIPMENT

COMMUNICATIONS SYSTEM (CONTINUED)

I = IN-HOUSE
V = VENDOR
M = ECS/TCS MODULE TEST (ET-1)

			ENVIRONMENTAL TESTING																													
ITEM NO.	PART NUMBER	NOMENCLATURE	CRITICALITY	HIGH TEMPERATURE	LOW TEMPERATURE	VIBRATION	SHOCK	TEMP/ALTITUDE	ACCELERATION	EMI	HUMIDITY	O_2 ATMOSPHERE	PRESSURE	BURST PRESSURE	LEAKAGE	LIFE/CYCLE	TEMP CONTROL	ACOUSTIC	STRUCTURAL	FUNGUS	SALT FOG	ENDURANCE	CORROSION	FLUID COMPAT:BILITY	VACUUM	HEAT REJECTION	RAPID DECOMPRESSION	TEMP SHOCK	PERFORMANCE	POWER/ALTITUDE	FOGGING	TEST SUPPORT
32	61B850005-7	CRDU	2			V				V																						
33	61B850005-11	CRDU	2		V	V		V	V	V					V	V																
34	61B850012-9	Hi Level Audio Amp	3		V	V		V	V	V	V				V	V																
35	61B850013-1	Coaxial Switch	2																											V		
36	61B850018-3	Teleprinter	3						V	V			V																			
37	61B850019-9	Interface Electronics Unit	3			V																										
38	61B850020-15	Timer Buffer	3		V	V		V	V	V	V					V																
39	61B850021-3	Digital Display Unit	3		V	V		V	V	V	V	V		V		V																
40	61C850001-17	TM Transmitter 10 Watt	2		V	V		V	V	V	V					V																
41	61C850013-3	Tracking Light Flash Head	3		V	V		V	V	V	V					V														V		
42	61C850013-9	Tracking Light Elec Unit	3		V	V		V	V	V	V					V														V		
43	61C850013-15, -17	Tracking Light Cables	3		V	V		V	V	V	V					V														V		
44	61B850020-21	Timer Buffer	3	V	V	V				V																						

TESTING REQUIRED TO QUALIFY AIRLOCK EQUIPMENT

CREW STATION

I = IN-HOUSE
V = VENDOR
M = ECS/TCS MODULE TEST (ET-1)

			ENVIRONMENTAL TESTING																													
ITEM NO.	PART NUMBER	NOMENCLATURE	CRITICALITY	HIGH TEMPERATURE	LOW TEMPERATURE	VIBRATION	SHOCK	TEMP/ALTITUDE	ACCELERATION	EMI	HUMIDITY	O_2 ATMOSPHERE	PRESSURE	BURST PRESSURE	LEAKAGE	LIFE/CYCLE	TEMP CONTROL	ACOUSTIC	STRUCTURAL	FUNGUS	SALT FOG	ENDURANCE	CORROSION	FLUID COMPATIBILITY	VACUUM	HEAT REJECTION	RAPID DECOMPRESSION	TEMP SHOCK	PERFORMANCE	POWER/ALTITUDE	FOGGING	TEST SUPPORT
1	61B810002-11, -15	Indicators	2	V	V	V			V	V	V	V	V		V	V													V			

APPENDIX C

DEVELOPMENT AND QUALIFICATION

TEST REQUEST

INDEX

TEST REQUEST INDEX

SYSTEM: ENVIRONMENTAL EXPOSURE

T.R. NO.	TITLE
061-010.01	Long Duration High Vacuum Exposure Test (MDC Report H205)
061-010.01.01	Short Duration Vacuum Test
061-010.02	Effects of Long Term Radiation Exposure on Airlock Components and Subsystems (MDC Report H205)
061-010.03	Airlock Materials and Components Corrosion Resistance Test
061-010.03.02	Corrosion Resistance Test of the Airlock Pressure Relief Valve, and Valve Subassemblies
061-010.04	Vacuum Exposure and Leakage Test for Circuit Breaker Panel and Tunnel Extension Test
061-010.06	Humidity Test of 3M's 401-A10 White Velvet Coating

TEST REQUEST INDEX

SYSTEM: MATERIALS & PROCESSES

T.R. NO.	TITLE
061-015.03	Configuration Sensitive Burn Test RTV 90
061-015.05	Airlock Coating Maintenance
061-015.06	Preparation and Verification of the Space Radiator Coating for Airlock
061-015.07	Evaluation of Fire Barrier Coating System
061-015.08	Evaluation of Low-Flammable Flexible Foam
061-015.09	Development of Low-Flammable Flexible Foam
061-015.10	Ultraviolet Stability of Thermal Control Coatings
061-015.11	Evaluation of Candidate Materials for Coating the Flexible Tunnel Extension on Airlock
061-015.12	Flammability Odor and Off-Gassing Evaluation of MMS 809 Insulite FP 301-1-T Shrink Sleeving
061-015.13	Evaluation of Hatch Seal Material
061-015.13.01	Airlock Initial Testing of Hatch Seals
061-015.14	Fire Detection - AAP
061-015.15	Evaluation of Low Flammable Coatings
061-015.16	Evaluation of Coatings for Gas Liquid Heat Exchanger
061-015.17	Flammability Test for Sound Absorption Panels
061-015.18	Air Contamination from Sound Absorption Panels
061-015.18.01	Airborne Contaminants from Rigimesh Sound Absorption Panels
061-015.19	Water System Corrosion Inhibitor Test
061-016.01	Ultraviolet Stability of Aluminum Pigmented Polyurethane Coating
061-016.02	Evaluation of Flared Tubes, Seals and Adapter Fittings
061-016.02.01	Evaluation of Airlock Flared Tube Connections with Conral Seals
061-016.03	Effect of Organic Brightners on Plated Copper Deposits
061-016.04	Reversion Characteristics of EC 1663 and RTV 90 When Enclosed
061-016.05	Evaluation of Low Flammable Coatings for Polymide Laminates

TEST REQUEST INDEX

SYSTEM: MATERIALS AND PROCESSES (CONTINUED)

T.R. NO.	TITLE
061-016.06	Evaluation of Laminar X500 (Polyurethane) and 3M's Nextel Brand Velvet Coating
061-016.07	Evaluation of Three Fluorocarbon Elastomer Based Coatings for Umbilical Stowage Container
061-016.08	Bonding Fluorel Coating to Titanium
061-016.09	Coolant Pump/Fluid Compatibility and Performance Tests (FC-75 and Freon E-1)
061-016.10	Evaluation of Hatch Seal Materials - Outgassing versus State-of-Cure
061-016.11	Lubricity Tests of Proposed Airlock Coolants (TM 256.1160)
061-016.12	Evaluation of the Flammability Characteristics of Freon E-1 and FC-75 in the Oxygen Atmosphere
061-016.13	Adhesion Tests for Fluorocarbon Elastomer Materials for Airlock
061-016.14	Ultraviolet Stability of Meteoroid Curtain
061-016.16	Flexible, Foam-in-Place, Polyimide Foam Stowage
061-016.17	Temperature-Altitude Testing of Wet Slug Tantalum Capacitors
061-016.17.01	Temperature-Altitude Testing of Wet Slug Tantalum Capacitors in a Potted Configuration
061-016.18	Simulated Corrosion of MDA Radiator Panels
061-016.19	Deaeration of Water Cooling Solution
061-016.20	Airlock: Development of Process Specification for Molding Forward Compartment Gas Circulation Duct Seal
061-016.23	Determine Torque Values for Airlock Cold Plating Fitting 52-83451-3
061-016.24	Bond Strength of EC1663/PR-1906 Sealant to Raychem 1230 TR Wire Insulation
061-016.25	Accelerated Vacuum Chamber Test of 61A350126 Hatch Seals
061-016.25.01	Airlock: Thirty Day Accelerated Temperature/Vacuum Test of 61A350126 Hatch Seal
061-016.25.02	30/66 Day Altitude Temperature Seal Test
061-016.26	Investigation of Cracking in Airlock O_2 Tank Dome-to-Polar Boss Welds
061-016.27	Vibration of Mosites 1062 to MMS 585

TEST REQUEST INDEX

SYSTEM: MATERIALS AND PROCESSES (CONTINUED)

T.R. NO.	TITLE
061-016.28	Continuity Loss - Multilayered Printed Wiring Boards
061-016.30	Effect of Airlock Systems Fluids on Cleaned and Pitted Stainless Steel Tubing
061-016.30.01	Vibration & Burst Pressure Test of Stainless/Pitted Airlock Tubing
061-016.35	Compatibility Tests - Roccal Sterox With Heat Exchanger Materials (TM 256.2675)
061-016.36	O_2 Regulator Relief Valve Low Temp. Impact Test (TM 256.1913)
061-016.37	Thermal Capacitor Wax Phase Change Characteristics (TM 252.415)
061-016.38	Thermal Capacitor Wax Compressibility
061-016.39	Wax Mixing (Tetradecane/Dodecane) Feasibility Tests
061-016.40	Freezing - Melting Characteristics of Tridecane and Undecane in Honeycomb Structures
061-016.41	Evaluation of Stress and Temperature Distribution in a Tridecane Wax Chamber
061-016.43	EA 934 Bond Sensitivity to Undecane and Tridecane
061-016.44	Thermal Capacitor Honeycomb Wax Chamber Bonding Evaluation
061-016.45	Determine Wax Permeability of EA034 Adhesive (TM 256.2399)
061-016.46	Restrained Wax Compressibility Test
061-016.47	Exposure of EA934 to Tridecane and Mutual Effects
061-016.48	Evaluation of Fatigue Loading on Bond Strength of the Thermal Capacitor Honeycomb Wax Chamber
061-016.49	P.S. 11052 Type III Adhesion
061-016.50	Metallographic Examination of Q-003 O_2 Tank Dome Assembly
061-016.50.01	Metallographic Examination of Q-001 O_2 Tank Dome Assembly
061-016.50.02	Metallographic Examination of Q-004A O_2 Tank Dome Assembly (TM 256.2984)
061-016.53	Compatibility Test 52-88705 Pressure (Ni Span C) with Airlock Water Additives (TM 256.2643)
061-016.55	Compatibility of Tygon Tubing with Various Water Solution (TM 256.2466 and 256.2657)

TEST REQUEST INDEX

SYSTEM: MATERIALS & PROCESSES (CONTINUED)

T.R. NO.	TITLE
061-016.55.01	Compatibility of Tygon Tubing with Type VII Water Solution (TM 256.2755)
061-016.55.02	Further Tygon Compatibility Tests
061-016.56	Pump Materials Corrosion/Compatibility Test with Modified Type III Solution (TM 256.2290)
061-016.57	Airlock Silicone O-Ring Failure
061-016.58	Compatibility of Fluorosilicone Elastomer Compounds with Various Water Solutions (TM 256.2868)
061-016.59	MMS 602 Compatibility with Copper (TM 256.2801)
061-016.60	Compatibility of Geon 8624 with Various Water Solutions (TM 256.2737)
061-016.60.01	Compatibility of Geon 8624 with Type V and Type VII Fluids (TM 256.2762)
061-016.61	61B830033 Pressure Gage Corrosion/Compatibility Test (TM 256.2830)
061-016.62	61B830033 Pressure Gage Compatibility/Life Test
061-016.63	Compatibility of Precision Compound 17387 with a Roccal Water Solution (TM 256.2822)
061-016.63.01	Compatibility Epoxy - Polyurethane Copolymer with 10% Roccal (TM 256.2353)
061-016.63.02	Compatibility Coastcraft 77-6 Fluorocarbon Elastomer with 10% Roccal (TM 256.2796)
061-016.63.03	Compatibility Fluorocarbon Elastomer (Parker Seal V3729) with 10% Roccal (TM 256.2751)
061-016.63.04	Compatibility Fluorocarbon Elastomer (Parco Comp. 9.75-9) with 10% Roccal
061-016.63.05	Compatibility Fluorocarbon Elastomer (Parker Seal 77-545) with 10% Roccal (TM 256.2766)
061-016.63.06	Compatibility Fluorocarbon Elastomer (Parco Comp. 979-75) with Roccal
061-016.63.07	Compatibility (Invelco 33F) with Roccal-Sterox (TM 256.2932)
061-016.63.08	Compatibility Lubricant (LG-160) with Roccal-Sterox (TM 256.2812)
061-016.63.09	Compatibility Silicone Rubber (PRPC Comp. 11715) with 10% Roccal (TM 256.2821)

TEST REQUEST INDEX

SYSTEM: MATERIALS & PROCESSES (CONTINUED)

T.R. NO.	TITLE
061-016.63.10	Compatibility Buna-N Parker Seal (Comp. PS-130-15) with 10% Roccal (TM 256.2773)
061-016.63.11	Compatibility Fluorinated Silicone and Dacron Fabric with 10% Roccal (TM 256.2735)
061-016.63.14	Compatibility Buna-N (MS28775-011) Rubber with 10% Roccal (TM 256.2823)
061-016.63.15	Compatibility of 10% Roccal Soln. with Metallics of Heat Exchanger Separator Plate System (TM 256.2739)
061-016.63.16	Dev. of Chem. Anal. Techniques for Separation of Organic Material for Roccal Soln. (TM 256.2869)
061-016.64	Bonding of Mosites 1079K
061-016.65	Compatibility of Precision Compound 11715 with Type V & VII Fluids (P.S. 13240) (TM 256.2824)
061-016.65.01	Compatibility of Parker Compound 5355-75 with Type V & VII Fluids (P.S. 13240) (TM 256.2818)
061-016.65.02	Compatibility of Parker Compound N398-7 with Type V & VII Water Solutions (TM 256.2788)
061-016.65.03	Compatibility of Parker Compound 77-545 with Type V and VII Solutions (TM 256.2319)
061-016.65.04	Compatibility of Epoxy-Polyurethane Copolymer with Type VII Fluid (TM 256.2375)
061-016.65.05	Compatibility of Redar Rubber from Life Support Umbilical with Type VII Fluid (TM 256.2820)
061-016.65.06	Compatibility of Epoxy (Hysol EA954) with Type VII Fluid (TM 256.2842)
061-016.65.07	Compatibility of Fluorolub LG-160 with Type VII Fluid (TM 256.2741)
061-016.65.08	Compatibility of Silicone O-Ring (1235-70) with Type VII Fluid (TM 256.2760)
061-016.65.09	Compatibility of Fused Woven Polypropylene with Type VII Fluid (TM 256.2756)
061-016.65.10	Compatibility of Silicone Rubber (MIL-R-5847D, CL 3-50 PG50) with Type VII Fluid (TM 256.2780)
061-016.65.11	Compatibility of Ethylene Propylene Elastomer (PRPC 3367) with Type VII Fluid (TM 256.2804)
061-016.65.13	Compatibility of Silastic SSU with Type VII Fluid (TM 256.2846)
061-016.65.14	Compatibility of Fairprene 44-005 with Type VII Fluid (TM 256.2825)

TEST REQUEST INDEX

SYSTEM: MATERIALS & PROCESSES (CONTINUED)

T.R. NO.	TITLE
061-016.65.15	Compatibility of Fluorocarbon Elastomer EMS 338, PRPC, Comp. 17387 with Type VII Fluid (TM 256.2852)
061-016.65.16	Compatibility of Coastcraft Comp. 77-6 with Type VII Fluid (TM 256.2734)
061-016.65.17	Compatibility of PTFC Primer with Type VII Fluid (TM 256.2827)
061-016.65.18	Compatibility of Krytox 240AC Grease with SUS Fluid Type VII (TM 256.2314)
061-016.65.20	Compatibility of PRPC Compound 107107A Fluorocarbon Elastomer O-Rings with Type VII Solution
061-016.67	Carbon Monoxide Off-Gassing from Activated Charcoal (TM 256.2350)
061-016.68	Compatibility of PRPC 3367 EDDM Compound with Type I Fluid (TM 256.2835)
061-016.69	Diaphragm Materials in Type I Fluid (TM 256.2384)
061-016.69.01	Diaphragm Materials in Type VII Fluid (TM 256.2908)

TEST REQUEST INDEX

SYSTEM: GROUND SUPPORT EQUIPMENT

T.R. NO.	TITLE
061-030.01	Static and Pressure Testing of 61E010045 Closure Assembly
061-030.03, .04 and .05	Proof Pressure Test of 61E010005, 61E010033 Closure Assemblies and Proof Loading of 61E010036 Truss Assembly
061-030.06	Structural Verification of the AM Transportation Trailer Casters, 61E010022
061-030.07	Compatibility of Coolant Fluids with the Solar Array Wing Simulators (SAWS) System Metallics at 160 Watts

SYSTEM: HATCHES

T.R. NO.	TITLE
061-045.01	Leakage and Mechanism Functional Test of the Airlock Internal Hatch
061-045.03 (Q)	Airlock Internal Hatch and Internal Hatch Mechanism Qual. Test
061-045.03.01 (Q)	AM Internal Hatch Seal Delta Qual

TEST REQUEST INDEX

SYSTEM: STRUCTURAL

T.R. NO.	TITLE
061-052.02.01	Airlock Module Test Requirements - Integrated Airlock/MDA Structural Verification Test Program
061-052.05 (Q)	Tunnel Extension Assembly Influence Coefficient and Stiffness Characteristics Test
061-052.07	Hand Tig Welding 6061-T6 Sheet
061-052.07.01	Hand Tig Welding 6061-T6 Drawn Tubing
061-052.09	Metallurgical and Mechanical Evaluation of Resistance Welded Production Airlock Tunnel
061-052.10	Effects of Cold Temperature on RTV 90, RTV 580 and RTV 8382
061-052.11	Stiffness and Fatigue Test of a Flexible Metal Bellows
061-052.12 (Q)	Airlock STS Window Qualification
061-052.13	Effect of Mission Temperature on Airlock/S-IVB Interface Joint Structural Characteristics
061-052.14	Element Test of Airlock Module STS Shear Panels
061-052.16 (Q)	Airlock Internal Hatch Window Qualification
061-052.20	Structural Test of AM Umbilical Stowage Container for Static and Cyclic Pressure Loading
061-052.23	Pressure Test of Coolant Pump Power Inverter Case
061-052.26	Strength of Glass Lens, Light Assembly, 61A800118-1 Under Impact Load
061-052.27 (Q)	STS Window Requalification
061-052.28	Airlock N_2 Tank Fracture Mechanics Investigation
061-052.29	61C830068 Flex Hose Test
061-052.30	Radiator Loop Connector Fitting (61A310139) Torque Test
061-052.31	"Frozen" Trunnion Bearing Test

TEST REQUEST INDEX

SYSTEM: MECHANISMS & FUNCTIONAL

T.R. NO.	TITLE
061-055.02	Discone Antenna Boom Functional Development Plan
061-055.02.01 (Q)	Qualification Test - Discone Antenna Boom Assembly
061-055.02.02 (Q)	Partial Requal - Discone Antenna Boom Assembly/ Release Mechanism
061-055.05	Design and Fabrication of Inertial Test Fixture and Simulated Truss Assemblies for ATM-DA Test Program
061-055.05.01	ATM Deployment Assembly Development Tests
061-055.05.02	ATM/DA Rigidizing System Development Tests
061-055.05.05 (Q)	ATM Deployment System Mechanical Component Qualification Test
061-055.05.07 (Q)	ATM/DA Rigidizing Mechanism Qualification Tests
061-055.05.09 (Q)	ATM/DA Acceptance/Qualification Test
061-055.05.10	ATM Deployment Reel Prolonged Stall Test
061-055.11	Deployment Reel Performance Verification
061-055.12	Deployment Assembly Cable Spring Rate
061-055.13	Discone Antenna Release Strap Creep Test

TEST REQUEST INDEX

SYSTEM: NOISE SUPPRESSION

T.R. NO.	TITLE
061-057.01	PLV Fan Noise Suppression System Evaluation
061-057.01.01	Noise Suppression System Evaluation of Suit Compressor and Rigimesh Panels
061-057.03	OWS Cooling Module Noise Suppression System Evaluation
061-057.05	Condensing Heat Exchanger Module Noise Suppression System Evaluation
061-057.07	Cabin Heat Exchanger Module Noise Suppression System Evaluation
061-057.09	Rigimesh Panel Sound Absorption Coefficient Measurement
061-057.10	OWS Interconnect Duct Fan Noise Suppression Evaluation
061-057.12	Tape Recorder Acoustic Survey
061-057.13	Teleprinter Acoustic Survey
061-057.14	Airlock Module Reverberation Study
061-057.15	On-Orbit Acoustic Noise Verification
061-057.17	Evaluation of Honeycomb Flow Straighteners for Acoustic Noise Reduction

TEST REQUEST INDEX

SYSTEM: STRUCTURAL DYNAMICS

T.R. NO.	TITLE
061-058.01.02	Dynamic Response Test of the Airlock/MDA
061-058.03	Vibration Test of Circuit Breaker Panel
061-058.04 (Q)	Vibration Test of a Quarter Panel of the Radiator Assembly
061-058.05	Vibration Development Test of an Airlock Type Specimen Bellows Assembly
061-058.06 (Q)	Vibration Qual. Test of Airlock Battery Module
061-058.09	PLV Fan/Heat Exchanger Acoustic
061-058.09.01	PLV Fan/Heat Exchanger Acoustic Test at 5.5 psia Atmosphere
061-058.09.02	PLV Fan Acoustic Test
061-058.10	Suit Compressor Acoustic Noise Test
061-058.14 (Q)	STS Window Cover and Window Cover Mechanism Qualification Test
061-058.19	Instrumentation Pressure Transducer Engineering Evaluation Vibration Testing
061-058.20 (Q)	Vibration Qualification of Radiator Coolant Line Connectors
061-058.21 (Q)	Vibration Qualification Test of AM Tunnel Stowage Cabinet
061-058.22 (Q)	Qual Test - Universal Indicator Isolation System
061-058.23	Vibration Test UV Fire Sensor Mounting Bracket
061-058.24 (Q)	Time Delay Relay Random Vibration Qualification Test
061-058.25 (Q)	Vibration Qualification of the #202 Stowage Cabinet, Portable Time & Water Separator Plate
061-058.26	Airlock Cable Bundle Static Load Vibration Test
061-058.28	Vibration Test -316, -320, -322 Circuit Breaker Panel
061-058.29 (Q)	Vibration Confidence Test - Circuit Breaker Panel

TEST REQUEST INDEX

SYSTEM: COMMUNICATIONS

T.R. NO.	TITLE
061-063.01	1/10 Scale CSM SSESM and S-IVB UHF Antenna Pattern
061-063.01.02	1/20 Scale Airlock Antenna Patterns and Full Scale Radiation Efficiency Measurements
061-063.01.04	1/20 Scale Airlock VHF Ranging Antenna Radiation Measurements (Quadrafilar Helix)
061-063.01.05	1/20 Scale Airlock VHF Ranging Antenna Radiation Measurements (Helix Antenna)
061-063.01.06	1/20 Scale Airlock UHF Ranging System Five Turn Helix Antenna Measurement
061-063.01.07	1/20 Scale Airlock VHF Ranging System 5 Turn Helix Antenna Measurement (6 polarization cuts)
061-063.02	One Year Leak Test of Sealed Telemetry Transmitter (52-85713-367)
061-063.03	Post Modification Acceptance Test of 52-85704-19 UHF Diplexer for Airlock
061-063.04 (Q)	Vibration Test of FAS Mounted UHF Whip Antennas
061-063.05 (Q)	Low Temperature Test on TM Transmitter P/N 52-85713-67
061-063.09 (Q)	Qualification Testing of Discone Antenna
061-063.10	Life Test of 52-85701-13 RF Coaxial Switch and 52-85714-23 DCS Relay Module
061-063.12	Electrical Overload Test of a Coolant Pump Power Inverter
061-063.13	Life Test of Electronic Timer
061-063.14	Life Test on DCS Receiver/Decoder 52-85714-27
061-063.15 (Q)	Qualification Testing of 61A850004 Airlock Audio Load Compensator
061-063.15.01 (Q)	Design Approval Life Testing of 61A850004 Airlock Audio Load Compensator
061-063.16	Thermal Vacuum Test on Airlock 2-Watt Telemetry Transmitter
061-063.17	Digital Command System & Command Relay Driver Unit Interface Development Test (DT-12)
061-063.18	Audio System/Caution & Warning System Compatibility Development Test (DT-13)
061-063.19	Apollo Audio Center and Voice System Compatibility Development Test (DT-14)

TEST REQUEST INDEX

SYSTEM: COMMUNICATIONS (CONTINUED)

T.R. NO.	TITLE
061-063.20	Speaker Intercom (61A850003) Thermal Environment Test (DT-17)
061-063.21	Speaker Intercom Acoustical Evaluation Test
061-063.21.01	61C850002 Speaker Acoustical Evaluation Development Test (DT-21)
061-063.22 (Q)	Speaker Intercom Qualification Test
061-063.22.01 (Q)	Design Approval Life Testing of 61A850003 Speaker Intercom Assembly
061-063.23 (Q)	Life and Altitude Qualification Tests on 61C850001 VHF 10-Watt Telemetry Transmitter
061-063.24	Audio Load Compensator Thermal Development Test
061-063.25 (Q)	Toggle Switch Assembly Verification Test
061-063.26 (Q)	Qualification Testing of Klaxon Unit
061-063.27 (Q)	Qualification Testing of 61A850007/61A850008 Light Dimmer Assembly
061-063.27.01 (Q)	Design Approval Life Testing of 61A850007 Airlock Light Dimmer Electronics Unit and 61A850008 Control Unit
061-063.28	Interference Test of the "Up-Data Link (UDL) Receiver" Part of the Quadriplexer
061-063.29 (Q)	Qualification Testing of 61A850006 Shunt Regulator
061-063.29.01 (Q)	Life/Cycle Test of Shunt Regulator
061-063.29.02	Shunt Regulator Mounting Bolt Fix Verification
061-063.30	Shunt Regulator Thermal Development Test (DT-24)
061-063.32	Digital Command System, Interface Electronics Unit, and Teleprinter Unit Interface Development Test (DT-27)
061-063.34 (Q)	61B850013-1 Coax Switch Power Altitude Test
061-063.35 (Q)	Quadriplexer 52-85703 Power Altitude Test
061-063.38 (Q)	High Temperature/Altitude Qualification Test on the 61C850001 UHF Telemetry Transmitter
061-063.39 (Q)	VHF Ranging Helix Antenna Qual Test
061-063.39.01 (Q)	Helix Antenna Vibration Tests
061-063.40 (Q)	Klaxon Delta Vibration
061-063.40.01	Klaxon Delta Vibration Test

TEST REQUEST INDEX

SYSTEM: COMMUNICATIONS (CONTINUED)

T.R. NO.	TITLE
061-063.41	Speaker Intercom Delta Vibration Test
061-063.42	VHF Helix Antenna Beam Width and Radiation Measurements Development Test (DT-31)
061-063.43	Speaker Intercom Assembly Dynamic Design Development Test
061-063.44 (Q)	Stub Antenna 61A840092-1 Qualification Test
061-063.44.01 (Q)	Stub Antenna Vibration Qual Test
061-063.45 (Q)	Light Dimmer Control Unit Switch 65700/AM Lamp Load Qual. Test
061-063.46	Lightweight Umbilical Electrical Development Test (DT-32)
061-063.48	61A850005 Klaxon Acoustical Evaluation Development Test
061-063.49	PCM Programmer/PCM Interface Box/Tape Recorder EMC Development
061-063.50 (Q)	61B850013-1 Coax Switch Delta Power Altitude Qualification Testing
061-063.52	Emergency Real Time Voice Downlink Capability (DT-45)
061-063.53	EBW Firing Circuit Shielding Effectiveness Test
061-063.54	Teleprinter Stopping Motor Humidity Survey of Component Parts
061-063.55	Audio Testing to Increase Gain of ALC (DT-48)
061-063.56	Quadriplexer Corona Testing (52-85703-23)
061-063.57	Coaxial Switch 61B850013-1 Vibration Qualification Test
061-063.60	Skylab Test Unit/Spaceflight Tracking and Data Network

TEST REQUEST INDEX

SYSTEM: INSTRUMENTATION

T.R. NO.	TITLE
061-064.02	Leakage/Life Test of Airlock Instrumentation Tape Recorder
061-064.04 (Q)	Nonoperating Vibration and Acceleration of Airlock Instrumentation Tape Recorder
061-064.05 (Q)	Qualification Test of Portable Timer
061-064.06 (Q)	Vibration of Airlock Signal Conditioners
061-064.07	PCM Programmer Hardline Prelaunch Load Evaluation Development Test
061-064.08 (Q)	Temperature Altitude and EMI Qual of Warning Signal Conditioners
061-064.09 (Q)	PPO_2 Transducer Life Test
061-064.10	M509 Experiment/AM Data Recovery System Engineering Evaluation Bench Test
061-064.11	Zero Gravity Experiments with the Skylab Fire Sensor (DT-35)
061-064.13	DC-DC Converter - Tape Recorder Transient Loads and DC-DC Converter Overload
061-064.14	Gas Flowmeter System Test (DT-47)
061-064.15 (Q)	QCM/CM - Mounting Bracket Survey and Random (Qual) Vibration
061-064.16	PPO_2 Sensor Drift Test
061-064.17	Spring Pin Stress Test - Fire Sensor Mounting Plate Knob Assembly
061-064.18	52-88715 CO_2 Detector Active Cartridge Life Test
061-064.18.01	52-88715-49 CO_2 Outlet Detector Life Test
061-064.19	Vibration Qualification Test of the 61B880064-11 Vibration Measuring Amplifier

TEST REQUEST INDEX

SYSTEM: ELECTRICAL

T.R. NO.	TITLE
061-066.01 (Q)	Qualification of 52-79705-67 Switch at High Current Conditions
061-066.04	Investigation of 52-79705 Toggle Switch, 52-79721 Circuit Breaker in 100% Oxygen Atmosphere
061-066.10	Circuit Breaker Evaluation
061-066.11	Physical Integrity Test of Teflon Convoluted Tubing
061-066.12	Wire Insulation and Accessory Flammability Test
061-066.15	Airlock Electrical Power System Battery Module Test (DT-10)
061-066.16	Functional & Environmental Evaluation of 52-79720-322 Fuse
061-066.17	Cycling Tests for AM Nickel-Cadmium Batteries
061-066.17.01	NiCad Battery Cycle
061-066.17.02	AM Battery Mission Test
061-066.17.03	AM Battery Mission Test Extension
061-066.18 (Q)	Diode Panel Qualification Test
061-066.19 (Q)	Foam Incapsulation Qualification Test Relay Panel (61T060056-13)
061-063.20 (Q)	Lamp Holder Assembly (61A820045-5)
061-066.21 (Q)	Filter Panel Assembly (61A762221)
061-066.22	Indicator Light Development Test
061-066.23 (Q)	Fire Sensor Control Panel
061-066.24 (Q)	Zero-G Conn Dust Cover
061-066.25	AM Cell Test (DT-39)
061-066.25.01	AM NiCad Cell Test
061-066.26	Electrical Wire Bundle Development Test
061-066.27 (Q)	SCR Panel Qualification Test (61A762345)
061-066.28 (Q)	Qual Test - Directional Lamp Assembly
061-066.29	AM Battery Life Cycle Test
061-066.29.01	AM Battery Life Cycle Spec #2
061-066.30 (Q)	Thermal Cycle Testing of Sequential Circuit Protection Panel Assembly 61A762358-1
061-066.31	STS Circuit Breaker Panel (Vibration)
061-066.31.01	Overstress Vib Test of STS Circuit Breaker Panel

TEST REQUEST INDEX

SYSTEM: ENVIRONMENTAL CONTROL

T.R. NO.	TITLE
061-068.02 (Q)	Oxygen Storage Tank Thermal Performance
061-068.03	Cryogenic O_2 Vessel Heater
061-068.04 (Q)	Performance and Qualification (Vibration Only) Tests of Astroaire Model 3301 Fan
061-068.05 (Q)	Leakage Tests of 52-83713-3 Shut-Off Valve
061-068.07 & .08 (Q)	Oxygen and Hydrogen Umbilical Hoses (Qualification Test Supplement)
061-068.10 (Q)	Performance Tests of 52-83701-15 Check Valve (Qualification Test Supplement)
061-068.11 (Q)	40°F Vernatherm Low Temperature Performance Test
061-068.12	Demonstration Test of Long Term Cryogenic Oxygen Storage Tank
061-068.15	Airlock Radiator Configuration Factors
061-068.17	Condensate Dump System Thermal Performance Test (DT-8)
061-068.18 (Q)	Life Test of the Airlock Condensing Heat Exchanger H_2O Separator Plates 52-83700-1193
061-068.19 (Q)	Endurance Test of the Cabin Water Dump Valve (P/N 52-83700-245)
061-068.20	Superinsulation Test
061-068.22	EVA/IVA Water Cooling Subsystem Development Test (DT-1)
061-068.27	Thermal Capacitor Test
061-068.29	PLV Fan And Cabin Heat Exchanger Flow Test
061-068.31	Condensing Heat Exchanger Gas "Break Thru" Point Test
061-068.34	Condensing Heat Exchanger Thermal Performance Test
061-068.35	ECS/TCS Module Endurance Test
061-068.35.01	Extension of Endurance Test on Instrumentation Hardware
061-068.36	Cabin Heat Exchanger/PLV Fan Subsystem Development Test
061-068.36.01	MOL Fan/Cabin Heat Exchanger Development Test
061-068.36.02	Heat Transfer and Condensation Loading/Flow Characteristics of a Silicone Coated Cabin Heat Exchanger

TEST REQUEST INDEX

SYSTEM: ENVIRONMENTAL CONTROL (CONTINUED)

T.R. NO.	TITLE
061-068.36.03	Cabin Heat Exchanger Reversed Coolant Flow Test
061-068.37	Water Servicing Development Test for Condensing Heat Exchanger
061-068.39	O_2/N_2 Two Gas Control System Development
061-068.41	ATM C&D Panel Cooling Subsystem Development Test
061-068.42 (Q)	Vernatherm Mixing Valve Performance Under Cycling Fluid Temperature Conditions
061-068.43 (Q)	Endurance Test Supplement for the Manual Shutoff Valve
061-068.44 (Q)	Supplemental Qualification Test of an Oxygen System Manual Shutoff Valve
061-068.47 (Q)	Qualification Test Supplement for the Water Check Valve
061-068.49 (Q)	Squeeze Bulb Vacuum Exposure Test: Endurance
061-068.53 (Q)	Thermal Capacitor Qual Test
061-068.54 (Q)	Endurance Test Supplement for Quick Disconnect Assemblies
061-068.55 (Q)	Airlock Compartment Duct/Bellows Qualification Test
061-068.55.01 (Q)	Duct Attach Bracket Redesign Verification
061-068.59	Water Separator Plate Assembly Performance
061-068.60 (Q)	Acceleration Qualification Test of the Water Tank
061-068.61	Temperature Control Valve Cycle and Temperature Altitude Tests
061-068.62 (Q)	Life Cycle and Burst Test of Coolant Reservoir
061-068.63 (Q)	Vibration Qualification Test of the Oxygen Heat Exchanger
061-068.64 (Q)	Qualification Test - Condensate Exit Assembly
061-068.65	Cabin Pressure Relief/Valve Freezing Development Test
061-068.66 (Q)	Qualification Test - Vibration and Burst Pressure - Coldplate
061-068.67	Space Radiator Convection Heat Transfer Element Test
061-068.69 (Q)	Selector and Pressure Relief Valve Cycle/Life Test
061-068.70 (Q)	Coolant Pump Assembly Vibration Test

TEST REQUEST INDEX

SYSTEM: ENVIRONMENTAL CONTROL (CONTINUED)

T.R. NO.	TITLE
061-068.71 (Q)	Cabin Pressure Relief Valve Cycle/Life Test
061-068.72 (Q)	Centrifugal Compressor Vibration Test
061-068.73 (Q)	Qualification Test Supplement for the Manual Shutoff Valve
061-068.74 (Q)	Water Tank Bladder Cycle/Life Test
061-068.76	Coolant System Thermal Development Test (DT-34)
061-068.77	Water Pump Gas Tolerance Development Test (DT-36)
061-068.77.01	100-Hour Life Cycle Test - Water Pump
061-068.79	Coolant System Dry Gas Leak Confidence (DT-38)
061-068.81	In-flight Servicing and Deservicing Test (LSU/PCU/Suit/C&D) (DT-41)
061-068.82 (Q)	Qual Test (Vib. and Life Cycle) Manual Shutoff Valve
061-068.83 (Q)	Endurance Test of Coolant Pump 52-83700-833 for Contingency Mode Operation
061-068.85	Water Pump Flush and Dry Confidence (DT-44)
061-068.86	Verification of 52-83700-461 O_2 Heat Exchanger Cleanliness Levels
061-068.87 (Q)	Radiator Bleed Valve Low Temp Qual Test
061-068.88	O_2/N_2 Regulator Performance Test at Low Temperature
061-068.88.01	O_2 Regulator Characteristics at Low Gas Inlet Temperature
061-068.89	Water Servicing and Gas Breakthrough Test for Condensate Heat Exchanger -1223 (DT-46)
061-068.89.01	Water Servicing Techniques for Plate Wetting to Alleviate Breakthrough Problem Condensate Heat Exchanger
061-068.89.03	Evaluation of Water Servicing Technique for Plate Using Squeeze Bulb and Spare Condensate Tank
061-068.90	Coolant Reservoir Performance Test
061-068.91	Stretch Pressure of the Cabin Heat Exchanger
061-068.92	OWS Thermal Capacitor (Undecane Filled) Melting/Freezing Characteristics
061-068.92.01	Honeycomb Thermal Capacitor Development Test
061-068.92.02	Prototype Honeycomb Thermal Capacitor Thermal Performance Tests - Tridecane Wax
061-068.92.03	Honeycomb Thermal Capacitor Undecane Wax Development Test

TEST REQUEST INDEX

SYSTEM: ENVIRONMENTAL CONTROL (CONTINUED)

T.R. NO.	TITLE
061-068.93 (Q)	AM Thermal Capacitor Qual
061-068.95 (Q)	Vibration Qual Test for QD Nipple
061-068.96	Thermal Capacitor Pre-Qual Thermal Performance
061-068.97	Cabin Heat Exchanger Vacuum Exposure Development Test
061-068.98	Thermal Capacitor Design Test (Stress/Thermal Performance)
061-168.99	ECS/TCS Skylab Test Unit
061-168.01 (Q)	Ground Cooling Heat Exchanger Random Vibration
061-168.02 (Q)	Thermal Capacitor Endurance Test
061-168.03 (Q)	Vibration Qual Test for 52-83708-165 and -167 QD Nipple and Coupler
061-168.04	Condensate System Performance Test Using Exit Port Nozzles (DT-49)
061-168.05	Condensing Heat Exchanger Vacuum Exposure Development Test
061-168.07 (Q)	Thermal Capacitor Module Insulation Verification
061-168.08	Water Separator Plate Functional Performance Test
061-168.09	52-88715-43 CO_2 Detector Verification Development Test Using T.R. 061-068.18 Testing Setup
061-168.09.01	52-88715-111 CO_2 Detector 52-88715-113 Active Cartridge and 52-88715-71 Passive Cartridge Life Test
061-168.10	61C830069 Water Pump/Suit Cooling Loop Additive Test
061-168.10.01	61C830069 Water Pump/Suit Cooling Loop Additive Test (Type VI Solution)
061-168.10.02	61C830069 Water Pump/Suit Cooling Loop Additive Test
061-168.10.05	Water Pump Evaluation, Type VII
061-168.10.06	Water Pump Evaluation, Type VII
061-168.11	Apollo CSM Pump Package Performance
061-168.12	PLSS Pump Performance
061-168.13	CHX to OWS Tank Dump Performance (DT-50)
061-168.14	Compatibility of Deionized OWS Water with 61C830069 Water Pump/SUS Fluid Test
061-168.15 (Q)	Qual Test for Modified CSM Pump

TEST REQUEST INDEX

SYSTEM: ENVIRONMENTAL CONTROL (CONTINUED)

T.R. NO.	TITLE
061-168.16	H_2O Servicing Deionizer MDAC-E P/N 61V830080 Performance Verification Test
061-168.17	52-83700-1211 Water Tanks Soak/Cycle Test
061-168.18	ATM Water (Type I) System Filter Clogging Test
061-168.19 (Q)	Qual. Test on MDAC-E Saddle Valve (61A830412-17)
061-168.19.01 (Q)	Requal. Test of Saddle Valve Assembly (61A830412-61)
061-168.19.02 (Q)	Qual. Test of GFE Saddle Valve (20M33247)
061-168.19.03 (Q)	Requal. Test of MDAC-E Saddle Valve (61A830417-47)
061-168.19.04	Delta Qual. Test of GFE Saddle Valve
061-168.21 (Q)	Qual. Test of Benton Model 2000-S Manual Shut-Off Valve
061-168.21.01 (Q)	Qual. Test of Benton Model 2000-S Manual Shut-Off Valve
061-168.23 (Q)	Qual. Test of 61A830416-1 Servicing Hose Assembly
061-168.23.01 (Q)	Qual. Test of 61A830416-1 Servicing Hose Assembly
061-168.24 (Q)	Storage Verification Test of the 61A830421-23 Repair Seal
061-168.25 (Q)	Pressure Cycle Test of 61A830355-13 H_2O Servicing Hose

APPENDIX D

ENVIRONMENTAL CONTROL SYSTEM/THERMAL CONTROL SYSTEM

SKYLAB TEST UNIT

TEST REQUEST

INDEX

TEST REQUEST INDEX

ECS/TCS STU TESTS CONDUCTED

T.R. NO.	TITLE
061-015-600.01	Life Umbilical - SUS Loop Operation SUS Water Loop operation-evaluated using two 60-foot LSU's in series.
061-015-600.02	U-1 Cold Coolant Simulation STU operation/simulation of Coolant Loop at system heat loads on U-1. This test was expanded to continuously operate the STU system throughout the Skylab mission. STU systems were operated in similar manner/modes as on U-1.
061-015-600.03	O_2 Regulator Cold Gas Check 120 psi O_2, Regulator operation evaluation at cold gas inlet temperature lower than qual. levels.
061-015-600.04	Primary O_2 Heat Exchanger Cold Gas Check Coolant System operation evaluation with cold O_2 gas simulation at Primary O_2 Heat Exchanger.
061-015-600.05	ATM Pump ΔP Light Trip Point ATM Water Loop operation to determine system time characteristics with ΔP light.
061-015-600.06	47° Vernatherm Valve Test Coolant System operation simulated a discrepant condition on U-1. Evaluated thermal shock on valve.
061-015-600.07	Thermal Capacitor Test Coolant System operation simulated proposed U-1 configuration.
061-015-600.08	SUS H/X Heat Dissipation Rate Test Coolant System operation evaluated system cooling rate during EVA with H/X in bypass mode.
061-015-600.09	Seal Integrity of Water Deionization Filter Ass'y. Verification of filter ass'y. seals after exposure to 130°F environment, similar to U-1 unit.
061-015-600.10	Coolant Pump Shut-Down & Start-up Test Coolant System operation; evaluated Coolant Pump flow and ΔP characteristics during an automatic switch-over of shut-down and start-up of pump.

TEST REQUEST INDEX

ECS/TCS STU TESTS CONDUCTED (CONTINUED)

T.R. NO.	TITLE
061-015-600.11	CO_2 Detector Filter Cartridge Performance Test Performance test on returned $PPCO_2$ cartridges from Skylab #2 mission.
061-015-600.12	47° Vernatherm Valve (TCV-B) Coolant System operation evaluated valve outlet temperature modulations with varied inlet temperature condition.
061-015-600.13	47° Vernatherm Valve Contamination Test Coolant System operation evaluated possibility of valve jamming with contamination (metal chips).
061-015-600.14	47° Vernatherm Valve Contamination Test Continuation of testing to conditions simulated in TR 600.12.
061-015-600.15	Mole Sieve Compressor Power Inverter Test Problem with Mole Sieve B compressor on U-1 Circuit Breaker opened due to excessive power draw during start-up current and voltage.
061-015-600.16	Simulated Leak Test on Primary Coolant Loop Suspected of Primary Coolant Loop leakage on U-1. Pump inlet pressure gradually decreased. STU test conducted to withdraw Coolanol 15 from Coolant Loop in incremental amounts, simulating a leakage condition, until pump cavitation occurs.
061-015-600.17	Materials exposure effect of Sun Rays (IR and UV) and Coolanol 15 Associated with the suspected Primary Coolant leakage on U-1; an Auxiliary STU Test was conducted to evaluate the capability of the SL-3 crew to locate the Coolant Loop leakage point by observing stained and/or color changes on various U-1 materials due to exposure to sun rays and leaking Coolanol 15.

ECS/TCS STU TESTS CONDUCTED (CONTINUED)

T.R. NO.	TITLE
061-015.600.18	Evaluation of Loop Coolanol Transfer Method Associated with suspected Primary Coolant Loop leakage on U-1; an Auxiliary STU test was initiated to determine the feasibility of fluid transfer between Coolant Loops on U-1. Test setup was terminated to conduct further test evaluations of the suspected Coolant Loop leakage on U-2, and also to evaluate the proposed Saddle Valve concept. No test effort was conducted versus this T.R.
061-015.600-19	Altitude Test of 2-Watt and 10-Watt Airlock Transmitters without Cold Plates Associated with suspected Primary Coolant Loop leakage on U-1; an Auxiliary STU Test was conducted to determine what duty cycle would be required to keep the transmitters operating temperatures below maximum allowable levels if no cooling available.
061-015-600.20	Saddle Valve Leaking/Flow Tests (Commercial Valves) Associated with suspected Primary Coolant Loop leakage on U-1; an Auxiliary STU test was conducted on commercial Saddle Valves to evaluate the concept of using this type of a valve/installation concept to add Coolanol to Coolant Loop.
061-015-600.21	Coolant Loop Fitting Leak Test Associated with suspected Primary Coolant Loop leakage on U-1; an Auxiliary STU test was conducted to determine leakage characteristics of several typical line connections used in the Coolant Loop.
061-015-600.22	CO_2 Cartridge Contamination Analysis Associated with suspected Primary Coolant Loop leakage on U-1; an Auxiliary STU test was conducted on the returned SL-2 $PPCO_2$ cartridges to check for Coolanol 15 contamination.

TEST REQUEST INDEX

ECS/TCS STU TESTS CONDUCTED (CONTINUED)

T.R. NO.	TITLE
061-015-600.23	Coolant Reservoir Test Associated with suspected Primary Coolant leakage on U-1; STU test conducted to determine the Coolant reservoir pressure and temperature relationship to aid in prediction of Coolant Loop performance.
061-015-600.24	Development Test MDAC-E Design Saddle Valve (61A830412) Associated with suspected Primary Coolant Loop Leakage on U-1; an Auxiliary STU test was conducted on a MDAC-E designed Saddle Valve prior to initiating a formal Qualification Test Program on production valves. Leakage, flow and ΔP characteristics of development valve were determined.
061-015-600.25	Development Test MDAC-E Design Saddle Valve (61A830412) Additional development tests of max./min. tube diameter fit checks, tube oversize wall puncture and leakage, and burst level tests were conducted on the Development Saddle Valve.
061-015-600.26	STU Thermal Vacuum Test with Modified Coolant Reservoir Module Associated with suspected Primary Coolant Loop leakage on U-1; the STU Coolant system was modified to include all (8) of the 52-83700-421 Coolant reservoirs same as on flight system. Testing was conducted (similar to the test effort of TR 600.23 above) to determine Coolant reservoir/system characteristics.
061-015-600.27	ATM C&D QD exposure to Coolanol 15 Associated with suspected Primary Coolant Loop Leakage on U-1; an Auxiliary STU test was conducted to determine if Coolanol 15 could be visually detected on a disconnected QD from the ATM C&D loop, assuming the ATM C&D water loop was contaminated with Coolanol 15.

TEST REQUEST INDEX

ECS/TCS STU TESTS CONDUCTED (CONTINUED)

T.R. NO.	TITLE
061-015-600.28	Coolant Pump Circuit Breaker Test Crew in U-1 attempted to turn on 2nd pump in secondary loop and caused the circuit breaker to open. Object of this test was to duplicate U-1 Coolant loop conditions and determine electrical characteristics when switching on pumps.
061-015-600.29	SL-3R Coolant System Service Kit Functional Test Pressure drop in U-1 Coolant systems indicated a loss of Coolanol. This test was conducted to determine adequacy of reservicing hardware and procedures associated with utilization of an OWS Portable Tank.
061-015-600.30	SL-4 Coolant System Service Kit Functional Test Pressure drop in U-1 Coolant systems indicated a loss of Coolanol. This test was conducted to determine adequacy of reservicing hardware and procedures associated with utilization of a CSM Fuel Tank.
061-015-600.31	Saddle Valve Development Test This test was conducted to determine adequacy of Saddle Valve design, including puncture seal characteristics.
061-015-600.32	LSU Pressure Test This test was conducted to determine if a long term serviced LSU could still withstand proof pressure.
061-015-600.33	New Saddle Valve Seal Test This test was conducted to determine leakage characteristics of MSFC fabricated seals (both cylindrical and curved).
061-015-600.34	SUS Water Pump Temperature Test This test was conducted to determine if the SUS water pump could operate without Coolant flow through SUS Heat Exchanger for an 1-1/2 hour period without exceeding temperature limits.
061-015-600.35	S/N 3 Saddle Valve Puncture on Pressurized Line and Installed Seal ID Measurement NASA MSFC reported leakage when a tube filled with Coolanol at 5 psig was punctured by a production Saddle Valve. This test was conducted to determine leakage characteristics of S/N 3 Saddle Valve with MSFC cylindrical molded seal at same test conditions.

TEST REQUEST INDEX

ECS/TCS STU TESTS CONDUCTED (CONTINUED)

T.R. NO.	TITLE
061-015-600.36	Free Gas Injection Effect on Coolant Pump During reservicing of Coolant System in U-1, free gas trapped in Saddle Valve would be injected into Coolant System. This test was conducted to determine if 3 scc of air injected 10" upstream of Coolant Pump would cause pump to cavitate.
061-015-600.37	Pressure Test of Saddle Valve Redundant Seal This test was conducted to determine pressure sealing capabilities of several materials including Fluorel coatings, Fluorosilicone Epoxy, and Viton sealants.
061-015-600.38	NUPRO Valve Test Reservicing the U-1 Coolant System using a Saddle Valve required the use of a qualified shut-off valve. This test was conducted to qualifiy the NUPRO shut-off valve.
061-015-600.39	Repair Fixture, 61A830421, Leak Test This test was conducted to determine sealing characteristics of a repair fixture which would be used in U-1 to seal a punctured hole in a Coolant System tube made by Saddle Valve installation in case the installation leaks.
061-015-600.40	Mole Sieve Flowmeter Test U-1 Mole Sieve "A" Flowmeter (F210) indicated low flow that activated C&W at about 25 cfm while Mole Sieve "B" Flowmeter (F211) indicated high flow (off scale) during period when AM fill valve was open. This test determined flowmeter characteristics with simulated U-1 conditions.
061-015-600.41	N_2 Flowrate Through 61A830355-13 and 61A830356 Hose Assemblies SL-4 Coolant Loop servicing procedure included an N_2 purge to remove any residual H_2O present before using the assembly to leak check the Saddle Valve. This test determined the N_2 flowrate expected for simulated inflight pressure conditions.

TEST REQUEST INDEX

ECS/TCS STU TESTS CONDUCTED (CONTINUED)

T.R. NO.	TITLE
061-015-600.42	Saddle Valve Redundant Seal-Coolant Leakage Test This test was conducted to determine sealing characteristics of Epoxy and Fluorosilicone materials by using 100 psig Coolanol in a Saddle Valve body
061-015-600.43	Coolant Loop Air Inclusion Test This test was conducted to determine if pump cavitation would occur as a result of air injection into the Coolant Loop downstream of the ECS simulator. A total of 126 STD $in.^3$ of air was injected in increments of 2, 4, 8, 16, 32, and 64 STD $in.^3$.
061-015-600.44	Effect of Coolant Loop Loss on AM Voltage Regulator This test was conducted to determine if a stabilization temperature exists at or less than 140°F for an AM Voltage regulator at low load, vacuum conditions with loss of the AM Coolant Loop.
061-015-600.45	OWS Stowage Test of 61A830416-1 Servicing Hose Assembly This test was conducted to verify storage procedure for the Hose Assembly to limit pressure buildup due to temperature to 50 psig.
061-015-600.46	Coolant Loop Reservoir Module Temperature/Time Stabilization Test This test was conducted to obtain Coolant temperature/time stabilization data required to refine thermal model which was utilized to predict Coolant Loop performance during reservicing period.
061-015-600.47	STU Coolant System Servicing MDAC-E Valve and Repair Seal Installation This test was conducted to check procedures for removing Saddle Valve and installing repair seal.
061-015-600.48	ATM Loop Gurgle Test The SL-3 crew reported gurgle-like sounds which they think came from the ATM H_2O pump. This test was conducted to cry and duplicate conditions which might cause a gurgle noise.

TEST REQUEST INDEX

ECS/TCS STU TESTS CONDUCTED (CONTINUED)

T.R. NO.	TITLE
061-015-600.49	Exploratory Test of the AM N_2 Regulator Performance Characteristics Throughout the SL-3 and SL-4 mission, the N_2 Regulator gradually decreased to or below the spec. limits. The purpose of this test was to determine if different gravity directions, inlet pressures, flow demands or combinations thereof, would change the flow characteristics of a typical regulator.
061-015-600.50	ATM Pump Start-Up Characteristics U-1 ATM Pump start up time was approximately 20 seconds. Normal pump start-up time is 2 to 3 seconds. The purpose of this test was to determine the cause of the longer pump start-up time.
061-015-600.51	Simulated Coolanol Leak in Mole Sieve Module Evaluation Test The passive $PPCO_2$ cartridges returned from the S/L-3 mission were analyzed for contamination with Coolanol. Approximately 2PPM of Coolanol 15 by weight, was detected from a 300 mg sample taken from the inlet of the passive cartridge. The objective or this test was to determine the quantity of Coolanol that could be removed by $PPCO_2$ cartridge, the condensing heat exchanger and the charcoal cannister by simulating a Coolanol leak inside the Mole Sieve module.
061-015-600.52	Coolant Loop Fittings Cold Temperature Soak Leakage Tests This test was conducted to determine the effect of reduced temperature on leakage characteristics of typical U-1 Coolant line connections. Test was conducted in support of evaluating the Primary and Secondary Coolant loop leakage on U-1.

TEST REQUEST INDEX

ECS/TCS STU TESTS CONDUCTED (CONTINUED)

T.R. NO.	TITLE
061-015-600.53	Coolant Servicing Tank Mass Measurement Conducted to verify that coolant expelled from the Coolant Servicing Tank (61A830417-1) could be determined by measuring the elapsed time to repressurize the gas side of the servicing tank. This test was not conducted.
061-015-600.54	ATM Pump Flow Cycle Test U-1 ATM Pump "B" tended to cycle between 190 to 250 lbs/hr. The purpose of this test was to determine if cycling is a characteristic of a high pump ΔP condition causing the relief valve to actuate.
061-015-600.55	ΔP Test of ATM Filter This test conducted on the 61C830066-3, S/N 18, ATM filter cartridge returned by the S/L-3 crew, to determine the filter ΔP at a 250 lb/hr flow rate.
061-015-600.56	Evaluation of Liquid Gas Separator Performance When Installed in ATM Loop U-1 ATM Loop pump performance indicated cyclic degradation which might have been caused by free gas in the loop. A contingency method to remove the free gas utilized the liquid/gas separator which was installed in the SUS loop. The purpose of this test was to determine liquid/gas separator performance and compatibility with the ATM loop water solution.
061-015-600.57	ATM Pump Performance with Blocked Line Condition U-1 ATM loop pump performance indicated cyclic operation which might have been caused by an obstruction in the loop. This test was conducted to compare pump performance characteristics for normal and for blocked line conditions.
061-015-600.58	ATM Water Pump Locked Rotor Test U-1 ATM loop pump performance indicated cyclic operation which might have been caused by a stalled pump. This test was conducted to determine the ATM water pump terminal temperature when 28 VDC power was applied while the pump rotor was stalled.

TEST REQUEST INDEX

ECS/TCS STU TESTS CONDUCTED (CONTINUED)

T.R. NO.	TITLE
061-015-600.59	ATM Pump Performance Comparison with PIA Data Two 61C830069-305 water pumps, S/N 131 and 133 were installed in STU since May 1973. This test was conducted during December 1973 to obtain performance data for comparison with PIA data.
061-015-600.60	ATM Loop Air Inclusion Test U-1 ATM pump flow decreased, low delta P light came on for three minutes, while pump noise stopped. This test was conducted to determine if a large air bubble in the water loop could cause this condition.
061-015-600.61	ATM Pump Stall Test In Vacuum Chamber The objectives of this test were the same as for TR 061-015-600.58. The water pump was exposed to vacuum pressure while installed in a simulated ATM water loop.
061-015-600.62	Water Pump Performance at Conditions Other Than SCD Requirements Specifications U-1 ATM Pump flow decrease seemed to coincide with main bus current fluctuations. This test was conducted to determine pump performance at power lead less than 22 VDC.

APPENDIX E

MISSION DISCREPANCIES

THIS APPENDIX LISTS ALL THE SIGNIFICANT AIRLOCK SYSTEM MISSION DISCREPANCIES. DISCREPANCY BACKGROUND, CORRECTIVE ACTION (IF ACCOMPLISHED) AND MISSION EFFECT ARE DISCUSSED.

SUBSYSTEM: ECS/TCS

DISCREPANCY	BACKGROUND/CONCLUSIONS	CORRECTIVE ACTION	MISSION EFFECT
PRIMARY COOLANT LOOP TCV-B CONTROL BELOW DESIGN TEMPERATURE VALUE (SL-1/2)	ON DOY 158 THE SUS #1 WATER AND PRIMARY TCV-B OUTLET COOLANT TEMPERATURES BEGAN TO DECREASE UNTIL THE EVA 1 C&W WAS TRIGGERED. BELIEVED TCV-B STICKING DUE TO LOOP CONTAMINATION.	NORMAL TCV-B PERFORMANCE WAS RESTORED ON DOY 160 BY PERMITTING THE LOOP TO WARM AND THEN PULSING THE TCV-B BY SIMULTANEOUSLY ACTIVATING TWO PUMPS.	NONE
SECONDARY COOLANT LOOP TCV-B BELOW DESIGN TEMPERATURE VALUE (SL-1/2)	AFTER COMPLETION OF DOY 158 EVA, CREW POSITIONED THE HEAT EXCHANGER COOLANT FLOW VALVE TO "BYPASS" AND TURNED SUS 2 LOOP OFF. SHORTLY AFTERWARD, SECONDARY COOLANT TEMPERATURE LOW C&W WAS TRIGGERED.	TCV-B WAS FREED BY PERMITTING THE LOOP TO WARM UP AND THEN PULSING TCV-B BY SIMULTANEOUSLY ACTIVATING TWO PUMPS.	NONE
	ON DOY 236 (SL-3) FOLLOWING EVA, TCV-B OUTLET TEMPERATURE AGAIN DECREASED BELOW THE NORMAL OPERATING RANGE; REMAINED LOW THROUGH SL-3 AND SL-4. BELIEVED TCV-B STICKING DUE TO CONTAMINATION IN COOLANT LOOP.	CORRECTIVE ACTION WAS NOT ATTEMPTED; DOY 265 EVA USED O2 FLOW COOLING WITHOUT PROBLEM. AFTER DOY 019 THE VALVE WAS MODULATING PROPERLY AS A RESULT OF THERMAL EFFECTS DURING EREP MANEUVERS AT HIGH BETA ANGLES.	NONE
LOSS OF INDICATION OF TOTAL PRIMARY LOOP FLOW (F214) (SL-1/2)	ON DOY 158, THE CREW ACTIVATED BOTH SUS LOOPS AND THEN SWITCHED THE HEAT EXCHANGER COOLANT FLOW (EVA/BYPASS) VALVES IN BOTH COOLANT LOOPS TO THE EVA POSITION. AFTER SWITCHING, PRIMARY LOOP TOTAL FLOW INDICATION WENT TO ZERO. CAUSE UNKNOWN.	NONE. LOOP OPERATION WAS ADEQUATELY DETERMINED FROM REMAINING PARAMETERS.	NONE

SUBSYSTEM: ECS/TCS

DISCREPANCY	BACKGROUND/CONCLUSIONS	CORRECTIVE ACTION	MISSION EFFECT
CONDENSATE ΔP LOSS (SL-1/2)	FIRST REPORT OF CONDENSATE ΔP LOSS OCCURRED ON DOY 158 DURING EVA PREPS. ΔP LOSS AGAIN REPORTED ON DOY 163 AND DOY 167/168. HIGHER THAN NORMAL LOSS DURING EVA ON DOY 170. ALSO ON DOY 211. ALL PERIODS OF LOSS OCCURRED WITH INTERFACE AT PANEL 393 TO OWS HOLDING TANK DISCONNECTED. AM CONDENSATE MODULE PRESSURE INTEGRITY TEST CONDUCTED ON DOY 169 SHOWED NO INDICATION OF PRESSURE LOSS. ON DOY 245, FOLLOWING A HOLDING TANK DUMP AND DISCONNECTION OF THE DUMP QD, THE ΔP BEGAN TO HOLD STEADY. IT IS SUSPECTED THAT THE LEAK WAS DUE TO A SIDE LOAD ON THE DUMP QD.	NONE. EVA WAS CONDUCTED SATISFACTORILY AND CONDENSATE COLLECTION WAS ADEQUATE USING OWS HOLDING TANK.	NONE
	FOLLOWING EVA ON DOY 034 (SL-4) ΔP AGAIN WENT BELOW NORMAL. PROBLEM ISOLATED TO LIQUID/GAS SEPARATOR QUICK DISCONNECT ON PANEL 217. CAUSE UNKNOWN.	CORRECTED BY DISCONNECTING QD ON PANEL 217 AND CAPPING ON CONDENSATE SIDE WITH CAPS PROVIDED ON SL-4.	NONE
IMPROPER NITROGEN REGULATOR OPERATING PRESSURE RANGE (SL-1/2)	BEGINNING ON DOY 156 N_2 REGULATED PRESSURE GRADUALLY DECREASED TO BELOW EXPECTED OPERATING RANGE OF 155 $\pm$10 PSIA. SIMILAR REG PRESSURE DOWNWARD TRENDS NOTED FOLLOWING SL-3 ACTIVATION. REGULATOR TESTING AND DATA ANALYSIS WAS INCONCLUSIVE. CAUSE UNKNOWN.	CYCLING REGULATOR TO OFF FOR PERIOD OF TIME RESTORED OPERATION TO ACCEPTABLE OPERATING PRESSURE RANGE. AFTER SL-4 ACTIVATION REGULATED PRESSURE STABILIZED WITHIN NORMAL OPERATING RANGE.	NONE

SUBSYSTEM: ECS/TCS

DISCREPANCY	BACKGROUND/CONCLUSIONS	CORRECTIVE ACTION	MISSION EFFECT
DECREASE IN AIRLOCK MODULE PRIMARY COOLANT LOOP PUMP INLET PRESSURE (SL-3)	LOW PRESSURE LIGHT INDICATION OBSERVED BY CREW ON DOY 217. TELEMETERED DATA SHOWED A CONTINUED DECREASE IN LOOP PRESSURE UNTIL A LOW OF 5.8 PSIA WAS REACHED AND THE LOOP WAS SHUT DOWN ON DOY 235. THERMAL ANALYSIS INDICATED A LOSS OF COOLANOL FLUID.	UTILIZED SECONDARY LOOP ONLY. PRIMARY LOOP SUCCESSFULLY RESERVICED WITH 7.7 LB. OF COOLANOL ON DOY 323. (SL-4)	NONE
DECREASE IN AIRLOCK MODULE SECONDARY COOLANT LOOP PUMP INLET PRESSURE (SL-3/SL-4)	ANALYSIS INDICATED A DECREASE IN THE COOLANOL MASS IN THE SECONDARY LOOP DURING THE STORAGE PERIODS BETWEEN SL-2 AND SL-3 AND BETWEEN SL-3 AND SL-4. COOLANOL MASS APPEARED RELATIVELY CONSTANT DURING SL-3 AND SL-4 MANNED PHASES.	KIT TO RESERVICE THE PRIMARY AND SECONDARY LOOP PROVIDED ON SL-4. - SECONDARY LOOP NOT RESERVICED. RESERVOIR LOW LIGHT ON MOMENTARILY ON LAST DAY OF MISSION.	NONE
DECREASING AIR FLOW IN OWS PLENUM CHAMBER (F0209) (SL-3)	A GRADUAL DECREASE IN MEASURED AIR FLOW WAS NOTED BEGINNING ON DOY 218. FLOW DROPPED FROM 164 CFM ON DOY 218 TO 130 CFM ON DOY 228. ON DOY 251 CREW CLEANED HEAT EXCHANGER VANES AND RESTORED NORMAL FLOW.	CREW PROCEDURE ESTABLISHED TO PERIODICALLY CLEAN HEAT EXCHANGER VANES.	NONE
LOW AIR FLOW IN OWS INTERCHANGE DUCT (F0205) (SL-3)	GRADUAL DECREASES IN FLOW FROM 116 CFM ON DOY 218 TO 60 CFM ON DOY 242. CLEANING OF INLET SCREEN AND REPLACEMENT OF FAN FAILED TO SOLVE PROBLEM. CAUSE UNKNOWN - SUSPECTED FLOWMETER DEGRADATION DUE TO SENSOR INLET CONTAMINATION.	NONE. TOTAL FLOW TO OWS WAS ADEQUATE FOR ENVIRONMENTAL CONTROL.	NONE
ATM CONTROL AND DISPLAY LOOP FLOW ERRATIC AND COOLANT LOOP "LOW PUMP ΔP" LIGHT "ON" (SL-3/SL-4)	ON DOY 265 AND 266 (SL-3) COOLANT FLOW BECAME ERRATIC (238 TO 75 LB/HR) WHILE OPERATING ON PUMP "A" AND THE CREW REPORTED A "GURGLING" NOISE OUTSIDE THE VEHICLE IN THE AREA OF THE ATM C&D PUMP MODULE. LOOP WAS SHUT DOWN AND CREW REPLACED LOOP FILTER. PUMPS "B" AND "C" WERE THEN OPERATED WITH NO RECURRENCE OF PROBLEM.	COOLANT LOOP FILTER REPLACED WITH ONBOARD SPARE. FILTER ANALYZED AFTER SL-3 AND FOUND CLEAN.	NONE

SUBSYSTEM: ECS/TCS

DISCREPANCY	BACKGROUND/CONCLUSIONS	CORRECTIVE ACTION	MISSION EFFECT
	ON DOY 322 (SL-4) LOOP WAS ACTIVATED USING PUMP "B." ON DOY 323 ERRATIC FLOW WAS OBSERVED AGAIN AND THE LOOP DEACTIVATED ON DOY 324. ON DOY 329 THE LOOP WAS REACTIVATED FOR TROUBLE-SHOOTING OF THE EREP VALVE POSITION AND ITS EFFECT ON FLOWRATES. ERRATIC FLOW STILL EVIDENT USING PUMP "C." COOLANT FLOWRATE WENT TO ZERO ON DOY 347 WHILE OPERATING ON PUMP "B" AND "LOW PUMP ΔP" ONBOARD LIGHT CAME ON. CREW INSTALLED LIQUID/GAS SEPARATOR (LGS) ON DOY 352 AND LOOP OPERATED FOR APPROXIMATELY 7 HOURS. FLOW WAS THEN NORMAL WITH PUMP "B" OPERATING. SUBSEQUENT OPERATION OF PUMPS WAS NOISY AND FLOWRATES (AFTER DOY 358) WERE ERRATIC.	DEAEREATION OF LOOP USING MDAC-E PROCEDURE AND LGS RESULTED IN NOMINAL AND STABLE FLOWRATES.	NONE
	ON DOY 004 THE LGS WAS REINSTALLED AND LOOP OPERATED FOR APPROXIMATELY 11 HOURS. IMMEDIATE OPERATION WAS NORMAL; SUBSEQUENTLY FLOW AGAIN BECAME ERRATIC. CAUSE OF ERRATIC FLOW AND PUMP NOISE BELIEVED DUE TO GAS IN THE LOOP.	PERIODIC DEAEREATION OF LOOP WOULD BE REQUIRED TO KEEP FLOW NORMAL.	NONE

SUBSYSTEM: INSTRUMENTATION

DISCREPANCY	BACKGROUND/CONCLUSIONS	CORRECTIVE ACTION	MISSION EFFECT
AUTOMATIC SWITCHOVER FROM THE PRIMARY TO THE SECONDARY COOLANT LOOP OCCURRED TWICE FOR NO APPARENT REASON (SL-1/2)	AUTO SWITCHOVER FROM THE PRIMARY AM COOLANT LOOP TO THE SECONDARY LOOP OCCURRED ON DOY 139 AND AGAIN ON DOY 140. SENSOR GROUP 1 WAS SUSPECT AND PRIMARY COOLANT LOOP WAS OPERATED SUBSEQUENTLY WITH ONLY SENSOR GROUP 2 ENABLED.	AUTO SWITCHOVER SENSOR GROUP #1 WAS DISABLED. SENSOR GROUP 2 OPERATED WITHOUT RECURRENCE OF SHUTDOWN.	NONE
MOLE SIEVE A AND B INLET $PPCO_2$ INDICATED LOW (D0209, D0213). (SL-1/2)	ON DOY 147, TELEMETRY INDICATED INLET $PPCO_2$ READINGS TO MOLE SIEVES A AND B DIFFERED AND WERE LOWER THAN THE OUTLET OF MOLE SIEVE A. FURTHER MONITORING INDICATED BOTH INLET SENSORS WERE READING LOW WHEN COMPARED WITH THE EXPECTED RANGE AND READINGS OF CABIN AMBIENT $PPCO_2$ TAKEN WITH THE M171 ANALYZER.	NONE. BOTH DETECTORS PERFORMED PRIMARY FUNCTION OF MONITORING MOLE SIEVE PERFORMANCE. M171 MASS SPECTROMETER PROVIDED PERIODIC CHECK OF $PPCO_2$ LEVEL. ZERO CALIBRATION CARTRIDGE, PROVIDED ON SL-3, USED ON DOY 346 - INDICATED POSITIVE ZERO SHIFT OF APPROXIMATELY 2 mmHg.	NONE
SECONDARY LOOP INVERTER 1 CIRCUIT BREAKER OPENED. (SL-1/2)	ON DOY 149 SECONDARY LOOP INVERTER 1/ PUMP A WAS ACTIVATED BY DCS COMMAND. CREW DETERMINED INVERTER 1 CIRCUIT BREAKER WAS OPEN. ANALYSIS OF TM DATA INDICATED PUMP ΔP HAD DROPPED SHARPLY PRIOR TO LOSS OF POWER TO THE INVERTER BUT NO ELECTRICAL CURRENT PULSE WAS DETECTED SUFFICIENT TO OPEN THE CIRCUIT BREAKER. A FAILURE IN THE INPUT CIRCUITS OF THE INVERTER SUSPECTED.	NONE. TROUBLESHOOTING PROCEDURE WAS DEVELOPED BUT WAS NOT USED BY CREW AS PUMPS B AND C PERFORMED NORMALLY. ON DOY 39 (EOM), PUMP A OPERATED NORMALLY BY GROUND COMMAND; INVERTER #1 FAILED TO OPERATE.	NONE
AM S/N 13 RECORDER FAILED TO RESPOND TO A PLAYBACK COMMAND. (SL-1/2)	ON DOY 159, THE TAPE RECORDER (T/R) IN POSITION #1 FAILED TO RESPOND TO A DUMP COMMAND RESULTING IN LOSS OF DATA. FAILURE WAS ISOLATED TO A BROKEN DRIVE BELT. T/R HAD EXCEEDED DESIGN LIFE.	REPLACED BY SPARE TAPE RECORDER (S/N 22). SPARE BELTS AND REPAIR KIT PROVIDED ON SL-4.	NONE

SUBSYSTEM: INSTRUMENTATION

DISCREPANCY	BACKGROUND/CONCLUSIONS	CORRECTIVE ACTION	MISSION EFFECT
SUS 1 FLOW INDICATION ERRATIC (F206) (SL-1/2)	ON DOY 170 AND 326 (SL-4) TELEMETERED FLOW INDICATION BECAME ERRATIC AND WENT TO ZERO. SUSPECT FLOWMETER BEARING FAILURE DUE TO PRELAUNCH LOOP SERVICING ACTIVITY.	NONE. SYSTEM TEMPERATURES WERE ADEQUATE TO MONITOR PERFORMANCE.	NONE
TAPE RECORDER S/N 22 FAILED TO RESPOND TO DUMP COMMAND (SL-3)	ON DOY 173 TAPE RECORDER DATA COULD NOT BE RECEIVED. SL-3 CREW DETERMINED CAUSE AS A BROKEN DRIVE BELT BETWEEN TAPE DRIVE MOTOR AND SPEED CONVERTER ASSY.	REPLACED BY S/N 32. ADDITIONAL SPARES (2) PROVIDED ON SL-3. REPAIR KIT AND PROCEDURE PROVIDED ON SL-4.	NONE
THE TM PARAMETER K374, 2-WATT/10-WATT COAX SWITCH POSITION, FAILED IN THE 2-WATT POSITION. (SL-3)	ON DOY 176, DURING A SPECIAL TROUBLESHOOTING TEST OF THE 10-WATT TRANSMITTER A, THE PARAMETER K374 CEASED CHANGING STATES AND CONTINUOUSLY INDICATED THE COAX SWITCH WAS IN THE 2-WATT POSITION. FAILURE COULD BE INSIDE THE COAX SWITCH, FILTER ASSEMBLY, HIGH LEVEL MULTIPLEXERS OR WIRING BETWEEN THESE COMPONENTS.	NONE. CASE TEMPERATURES AND CHANGES IN SIGNAL STRENGTH AT TIME OF SWITCHING PROVIDED POSITIVE INDICATIONS THAT SWITCHING TOOK PLACE.	NONE
MOL SIEVE B SECONDARY FAN CIRCUIT BREAKER OPENED (SL-3)	ON DOY 209 DURING ACTUATION OF MOL SIEVE "B," CB OPENED WHEN FAN WAS TURNED ON. TROUBLESHOOTING INDICATED PROBLEM WAS WITH INVERTER AND/OR ELECTRICAL CIRCUITRY; CIRCUIT BREAKER WAS CLOSED WITH NO LOAD AND WITH A REPLACEMENT FAN AND DID NOT OPEN, AND REPLACEMENT FAN DID NOT RUN.	PRIMARY FAN WAS SELECTED AND PERFORMANCE WAS SATISFACTORY. FAN JUMPER-BUNDLE PROVIDED FOR SL-4.	NONE
DURING SL-3 ACTIVATION S/N 50 PPO_2 SENSOR WOULD NOT LOCK IN POSITION #2 ON PANEL 225 O_2/N_2 MODULE (SL-3)	ON DOY 212 AT SL-3 ACTIVATION, ALL SIX REPLACEMENT SENSORS WERE TRIAL FITTED BY THE CREW. ALL SENSORS FIT BUT NONE LOCKED IN PLACE IN POSITION #2.	NONE. S/N 50 REPLACEMENT SENSOR WAS INSTALLED IN LOCATION #2 BUT IN THE UNLOCKED POSITION AND OPERATED ACCEPTABLY DURING SL-3 AND SL-4.	NONE

SUBSYSTEM: INSTRUMENTATION

DISCREPANCY	BACKGROUND/CONCLUSIONS	CORRECTIVE ACTION	MISSION EFFECT
$PPCO_2$ DETECTOR "O"-RING SEAL FOR MOLE SIEVE B INLET WAS FOUND TO BE SEATED IMPROPERLY. (SL-3)	MOLE SIEVE B INLET $PPCO_2$ INDICATION VARIED ERRATICALLY BETWEEN 0 MMHG AND OFF-SCALE HIGH AFTER DETECTOR ACTIVATION ON DOY 212. TROUBLESHOOTING PROCEDURE SUBMITTED ON DOY 213. PROCEDURE IMPLEMENTED ON DOY 254 AND CREW FOUND "O"-RING WAS NOT SEATED PROPERLY. SEAL REINSTALLED AND INDICATION STABILIZED AT A LOWER THAN NOMINAL VALUE. INDICATION WAS AGAIN ABNORMAL FOLLOWING INSTALLATION OF CARTRIDGES AFTER THE ZERO-CALIBRATION ON DOY 256. "O"-RING SEAL INSPECTED AND FOUND SLIGHTLY DIRTY. SEAL CLEANED AND REINSTALLED AND READING RETURNED TO STABILIZED BUT LOW VALUE SIMILAR TO INDICATION DURING SL-2.	REDUNDANT SENSOR ON MOLE SIEVE A PERFORMED NORMALLY AND AGREED WITHIN 1.4 MMHG $PPCO_2$ OF THE M171 READING. REPAIR KIT CONTAINING FOUR "O"-RING SEALS WAS PROVIDED ON SL-4.	NONE
OWS LOW LEVEL MULTIPLEXER "B" INTERMITTENT OPERATION (SL-3)	ON DOY 215 THE MULTIPLEXER EXHIBITED ERRATIC OPERATION. HIGH TEMPERATURE TESTS CONDUCTED AT MDAC-E INDICATED FAILURE WAS TEMPERATURE DEPENDENT BUT NOT CONSISTENTLY REPEATABLE. TEST RESULTS WERE INCONCLUSIVE. THE ON-BOARD MULTIPLEXER RETURNED TO OPERATION ON OCCASION.	NONE. NONE OF THE MEASUREMENTS WERE OF A CRITICAL NATURE.	NONE

SUBSYSTEM: INSTRUMENTATION

DISCREPANCY	BACKGROUND/CONCLUSIONS	CORRECTIVE ACTION	MISSION EFFECT
ON-BOARD MOLECULAR SIEVE TEMPERATURE DISPLAY METERS READING LOW (SL-3)	ON DOY 219 THE ON-BOARD MOLECULAR SIEVE HEAT EXCHANGER OUTLET GAS TEMPERATURE INDICATED 36°F FOR SIEVE "A" AND 25°F FOR SIEVE "B" WHILE THE GROUND TELEMETRY READINGS WERE 51°F FOR "A" AND 46°F FOR "B." ON-BOARD INDICATIONS BELIEVED LOW SINCE THE COOLANT INLET TEMPERATURES TO THE CONDENSING HEAT EXCHANGER WERE 47°F AT THE TIME AND GAS OUTLET TEMPERATURES MUST BE HIGHER THAN COOLANT INLET TEMPERATURES. ONBOARD INDICATION RETURNED TO NORMAL DURING SL-4 ON DOY 324. CAUSE UNKNOWN.	NONE. REDUNDANT MONITORING PROVIDED BY TM.	NONE
TAPE RECORDER S/N 30 MOTION MONITOR CIRCUIT OUTPUT VOLTAGE FLUCTUATIONS (SL-3)	TAPE MOTION MONITOR WAS OBSERVED BY THE GROUND TO BE FLUCTUATING DURING DATA DUMPS (DOY 222). IT HAD BEEN ESTABLISHED BY MDAC-E AND RECOGNIZED BY THE NASA THAT THE PHOTOCELL USED IN THIS TAPE RECORDER MIGHT DEGRADE DURING LONG DARK STORAGE PERIODS.	NONE. RECEPTION OF PROPERLY SYNCHRONIZED DATA VERIFIED MOTION.	NONE
QUARTZ CRYSTAL MICRO-BALANCE (QCM) #1 FINE OUTPUT WAS BELOW SCALE (SL-3)	ON DOY 232 THE FINE OUTPUT OF QCM #1 (M016) BECAME ERRATIC AND SUBSEQUENTLY WENT BELOW SCALE. IT WAS SUSPECTED THAT THE SIGNAL CONDITIONER WHICH EXPANDS THE QCM OUTPUT FAILED.	NONE POSSIBLE. CONTAMINATION DATA FROM M015 (QCM #1 COURSE MASS OUT) REMAINED SATISFACTORY.	NONE
TAPE RECORDER S/N 28 EXHIBITED EXCESSIVE BIT ERRORS DURING DATA DUMP (SL-3)	TAPE RECORDER OUTPUT WAS DEGRADED DURING DATA DUMP (DOY 256). CREW TROUBLESHOOTING ESTABLISHED TAPE WAS OFF OF DRIVE CAPSTANS. THE TAPE RECORDER HAD EXCEEDED DESIGN LIFE.	REPLACED BY ONBOARD SPARE S/N 23. CREW CORRECTED TAPE PATH AND STOWED TAPE RECORDER FOR FUTURE USE.	NONE

SUBSYSTEM: INSTRUMENTATION

DISCREPANCY	BACKGROUND/CONCLUSIONS	CORRECTIVE ACTION	MISSION EFFECT
TAPE RECORDER S/N 32 MOTION MONITOR CIRCUIT OUTPUT VOLTAGE FLUCTUATIONS (SL-3)	TAPE MOTION MONITOR WAS OBSERVED BY GROUND TO BE INTERMITTENT, DURING DATA DUMPS (DOY 265). THE MOTION MONITOR CIRCUIT OUTPUT VOLTAGE FLUCTUATED IN THE RECORD MODE AS WELL AS THE DUMP MODE, SUCH THAT THE ONBOARD DATA AND VOICE RECORD LIGHTS CYCLED DURING RECORDINGS. DISCREPANCY SIMILAR TO THOSE OBSERVED ON TAPE RECORDER S/N 30 (PHOTOCELL DEGRADATION).	NONE. RECEPTION OF PROPERLY SYNCHRONIZED DATA VERIFIED MOTION.	NONE
PORTABLE TIMER FAILURE TO SET. (SL-3)	BROKEN/DISLOCATED MINUTE INDEX ASSY COMPRESSION SPRING OR THE TIMER BATTERY CHASSIS PLUG WAS BINDING THE MINUTE INDEX ASSY.	TIMER REPLACED WITH ONBOARD SPARE.	NONE
EXP 2/DATA 2 RECORDER FAST FORWARD COMMAND COULD NOT BE RESET (SL-4)	DURING TROUBLESHOOTING OF DELAYED TIME DATA DROPOUTS ON DOY 315, EXP 2/DATA 2 FAST FORWARD WAS COMMANDED. ATTEMPTS TO REMOVE COMMAND WERE UNSUCCESSFUL. CONTAMINATION IN DCS REAL TIME RELAY MODULE WAS SUSPECTED.	ON DOY 317 ALTERNATE SET/RESET COMMANDS RESULTED IN RESET OF FAST FORWARD. THIS COMMAND WAS REMOVED FROM THE GROUND COMMAND COMPUTER TO PREVENT AN INADVERTENT FAST FORWARD COMMAND.	NONE
LOW LEVEL MULTIPLEXER "P" NOISY (8 PARAMETERS) (SL-4)	ON DOY 349 EXCESSIVE NOISE APPEARED ON 8 PARAMETERS OF MUX. "P." ANALYTICAL EVALUATION DETERMINED THE PROBABLE CAUSE TO BE A CHANGE IN TURN-ON CHARACTERISTICS OF THE SECOND TIER SWITCH ASSOCIATED WITH THESE PARAMETERS. ATTEMPTS TO DUPLICATE THE PROBLEM FAILED.	NONE. PARAMETERS WERE NOT CRITICAL TO MISSION SUCCESS. GROSS INDICATION OF PERFORMANCE WAS POSSIBLE.	NONE

SUBSYSTEM: INSTRUMENTATION

DISCREPANCY	BACKGROUND/CONCLUSIONS	CORRECTIVE ACTION	MISSION EFFECT
ERRATIC DATA FROM ALL SEVEN AM LOW LEVEL MULTIPLEXERS AND FROM NINE CHANNELS IN THE TWO PROGRAMMERS. (SL-4)	ON DOY 357 ERRATIC DATA FROM THE FIRST 8 DATA CHANNELS OF THE LOW LEVEL MULTIPLEXERS AND THE 80 PSP CHANNELS OF THE PRIMARY PROGRAMMER WAS OBSERVED. ATTEMPTS TO CLEAR THE PROBLEM BY SELECTING REDUNDANT EQUIPMENT WAS UNSUCCESSFUL. PROBLEM CORRECTED ITSELF BUT RECURRED AGAIN ON DOY 359. ATTEMPTS TO SIMULATE THE PROBLEM WERE ONLY PARTIALLY SUCCESSFUL. THE MOST PROBABLE CAUSE WAS A VOLTAGE PROPAGATED ON THE 3MV (15%) REFERENCE LINE CONNECTING ALL THE AFFECTED EQUIPMENT.	NONE. THE DATA FROM ALL THE MULTIPLEXERS EXCEPT THE FIRST EIGHT CHANNELS OF MUX "P" WAS RECOVERABLE BY VISUAL EXAMINATION OF STRIP CHARTS.	NONE
LOSS OF INDICATION OF PRIMARY LOOP TCV-B HOT INLET FLOW (F212) (SL-4)	PRIMARY LOOP RESERVICED WITH COOLANOL ON DOY 323. DURING LEAK CHECK OF RESERVICING SADDLE VALVE, F212 INDICATION WENT TO ZERO AS TWO COOLANT PUMPS WERE ACTIVATED. SUSPECTED FLOWMETER FAILURE.	NONE. LOOP OPERATION WAS ADEQUATELY DETERMINED FROM REMAINING PARAMETERS.	NONE
OWS HIGH LEVEL MULTIPLEXER "J" NOISY OUTPUT (SL-4)	ON DOY 011 THE MULTIPLEXER EXHIBITED ERRONEOUS DATA OUTPUT DURING EREP MANEUVERS. RECOVERY WAS AFFECTED ON OCCASION. PROBLEM SUSPECTED TO BE DUE TO THERMAL CYCLING EFFECTS.	NONE. DATA COULD BE EXTRAPOLATED.	NONE
TAPE RECORDER S/N 32 FAILED TO DUMP DATA COMPLETELY. (SL-4)	RECORDER HAD INCOMPLETE DATA DUMP ON DOY 019. THE TAPE RECORDER HAD EXCEEDED DESIGN LIFE. UNKNOWN CAUSE.	REPLACED BY ONBOARD SPARE S/N 21.	NONE

SUBSYSTEM: COMMUNICATIONS

DISCREPANCY	BACKGROUND/CONCLUSIONS	CORRECTIVE ACTION	MISSION EFFECT
LOW SIGNAL STRENGTH FROM AM 10-WATT TRANSMITTER A. (SL-1/2)	BEGINNING DOY 158 THE AM 10-WATT TRANSMITTER A EXHIBITED PERIODS OF LOW SIGNAL STRENGTH WHICH RESULTED IN LOSS OF SOME DATA. THE SIGNAL STRENGTH STABILIZED BELOW NORMAL. SUSPECTED A FAILURE OF R.F. POWER AMPLIFIER.	NONE. COMPLETE DATA TRANSMISSION WAS MAINTAINED USING TWO-WATT TRANSMITTER "A" FOR REAL TIME DATA.	NONE
C&W FIRE SENSOR FAILED TEST (SL-1/2)	DURING CHECKOUT OF C&W ON DOY 160 FIRE SENSOR 392-2 FAILED TO INDICATE FIRE ALARM CLOSURE. TROUBLESHOOTING ISOLATED DEFECT TO SIDE #2 OF FIRE SENSOR CONTROL PANEL.	PANEL REPLACED WITH ONBOARD SPARE. FAILED PART COULD HAVE BEEN USED FOR SPARE IN LOCATION WHERE SIDE #1 ONLY WAS REQUIRED.	NONE
NO C&W INDICATION FROM LOW ΔP AT PUMP STARTUP ON SUS LOOP 1 AT PANEL 317 (K931) (SL-1/2)	NO C&W INDICATIONS OCCURRED FROM LOW ΔP ON DOY 170 AND DOY 218 AT SUS #1 PUMP STARTUP. SUSPECTED SENSOR FAILURE.	NONE. SYSTEM TEMPERATURES AND CREW COMMENTS VERIFIED ADEQUATE SYSTEM PERFORMANCE.	NONE
CREW VOICE DISTORTION OVER AUDIO RECORDER CHANNEL B (SL-3)	AUDIO CHANNEL B RECORDED VOICE WAS DISTORTED ON DOY 212. CREW TROUBLESHOOTING AND MDAC-E STU/STDN TESTING INDICATED TROUBLE WAS INTERNAL TO THE AUDIO LOAD COMPENSATOR. MALFUNCTION OF A POWER SUPPLY IN THE AUDIO LOAD COMPENSATOR RESULTED IN A SIMILAR FAILURE SYMPTOM.	EMERG/TAPE RECORDER VOICE CABLE PROVIDED ON SL-4 AS AN ALTERNATE METHOD OF OBTAINING AUDIO TAPE RECORDING USING SWS MICROPHONE LINE.	NONE
TELEPRINTER PAPER FEED FAILURE (SL-3)	INSPECTION ON DOY 219 REVEALED RUBBER GROMMET HAD SLIPPED ON METAL BUSHING IN TELEPRINTER PAPER DRIVE ASSY.	CREW REPLACED TELEPRINTER WITH ONBOARD SPARE. REPAIR KIT PROVIDED ON SL-4.	NONE

SUBSYSTEM: COMMUNICATIONS

DISCREPANCY	BACKGROUND/CONCLUSIONS	CORRECTIVE ACTION	MISSION EFFECT
ICOM/XMIT SWITCH ON THE SIA AT OWS STATION 540 INOPERATIVE (SL-3)	A MECHANICAL MALFUNCTION OF THE ICOM/XMIT SWITCH WAS NOTED BY CREW ON DOY 229.	SIA S/N 1060, REPLACED BY CREW ON DOY 230 WITH ONBOARD SPARE, S/N 1059.	NONE
PRIMARY TIME REFERENCE SYSTEM (TRS) ERRATIC OUTPUTS (SL-3)	ON DOY 236, SHORTLY AFTER GYRO 6-PACK INSTALLATION, CREW REPORTED ERRATIC TIMING FROM DIGITAL DISPLAY UNITS. GROUND INDICATIONS WERE UNAFFECTED. ON DOY 237, CREW SELECTED THE SECONDARY TIMER AND TRS RESUMED NORMAL OPERATION. LABORATORY TESTS SIMULATED SYMPTOMS TWO WAYS: 1) BY FORCING OSCILLATOR TO DRIFT EXCESSIVELY AND 2) BY INTRODUCING ELECTROMAGNETIC INTERFERENCE (EMI). SUSPECTED EMI SINCE OSCILLATOR DRIFT IS NOT AN HISTORICAL FAILURE MODE.	SECONDARY TIMER SELECTED. NO DATA CORRELATION WAS LOST. NO DIGITAL COMMAND SYSTEM SWITCHOVER CAPABILITY WAS LOST.	NONE
SECONDARY TIME REFERENCE SYSTEM (TRS) ERRATIC OUTPUTS (SL-3)	ON DOY 262, GROUND AND ONBOARD DISPLAYS OF ELAPSED TIME DISPLAYED NUMEROUS "JUMPS" OF 2 HOURS, 16 MINUTES. PRIMARY TIMER WAS RESELECTED AND TRS OUTPUTS RETURNED TO NORMAL. SUBSEQUENT RETURN TO SECONDARY TIMER FOR TROUBLESHOOTING PURPOSES REVEALED ITS ASSOCIATED PROBLEM HAD ALSO DISAPPEARED. ANOMALY OCCURRED DURING PERIODS OF HIGH ACTIVITY AND WAS ALSO SUSPECTED TO BE EMI RELATED.	PRIMARY TIMER RESELECTED. NO DATA TIME CORRELATION WAS LOST. NO DIGITAL COMMAND SYSTEM SWITCHOVER CAPABILITY WAS LOST.	NONE

SUBSYSTEM: COMMUNICATIONS

DISCREPANCY	BACKGROUND/CONCLUSIONS	CORRECTIVE ACTION	MISSION EFFECT
OSCILLATIONS AND LOW VOLUME IN AUDIO CHANNEL B EARPHONE CIRCUIT. (SL-3)	ON DOY 265, CREW REPORTED A 4.0 HZ AUDIO OSCILLATION AND A CONCURRENT 50% VOLUME LOSS ON THE CHANNEL B EARPHONE CIRCUIT FOLLOWING AN EXTRAVEHICULAR-ACTIVITY (EVA). TROUBLESHOOTING BY CREW APPARENTLY ISOLATED PROBLEM WITHIN CHANNEL B AUDIO LOAD COMPENSATOR SECONDARY EARPHONE AMPLIFIER. TWO HOURS AFTER OCCURRENCE OF PROBLEM, CREW REPORTED BOTH VOLUME LOSS AND OSCILLATION HAD DISAPPEARED. PROBLEM HAD NOT RECURRED AS OF SL-3 DEACTIVATION DOY 268. AFTER CSM UNDOCKING FROM SWS, CREW REPORTED OSCILLATION HAD RECURRED IN CSM.	NONE. CREW REPORTED THAT INTELLIGIBLE CONVERSATION WAS POSSIBLE AT ALL TIMES.	NONE
FAILURE OF MICROPHONE CIRCUITRY IN SPEAKER INTERCOM ASSEMBLY (SIA) AT MDA LOCATION 131 (SL-4)	ON DOY 333 CREW REPORTED THEY WERE UNABLE TO INITIATE VOICE COMMUNICATIONS AT SIA 131. RECEPTION WAS UNAFFECTED. CREW TROUBLESHOOTING DETERMINED THAT FAILURE WAS IN THE MICROPHONE CIRCUITRY.	SIA, S/N 1065, WAS REPLACED BY ONBOARD SPARE, S/N 1058.	NONE
TELEMETRY TRANSMITTER "C" FAILED TO RESPOND TO "ON" COMMANDS (SL-4)	ON THREE OCCASIONS, DOY'S 335, 353 AND 356, TRANSMITTER "C" WAS COMMANDED "ON" BUT NO RF CARRIER WAS DETECTED AT THE SITES. TRANSMITTER WAS RETURNED TO PROPER OPERATION BY GROUND COMMAND ON DOY 335 AND 353. ON DOY 356 THE CIRCUIT BREAKER WAS OBSERVED OPEN BY THE CREW. IT WAS CLOSED AND TRANSMITTER OPERATION WAS NORMAL. PROBLEM MAY HAVE BEEN CAUSED BY CONTAMINATION ON RELAY CONTACTS WHICH WAS CLEARED BY SUBSEQUENT OPERATION OR AN INTERMITTENT PROBLEM INTERNAL TO THE TRANSMITTER.	CREW CLOSED CIRCUIT BREAKER FOR DOY 356 OCCURRENCE.	NONE

SUBSYSTEM: COMMUNICATIONS

DISCREPANCY	BACKGROUND/CONCLUSIONS	CORRECTIVE ACTION	MISSION EFFECT
LOSS OF TELEMETRY TRANSMITTER "B" CARRIER (SL-4)	ON DOY 017 TRANSMITTER "B" (10 WATT) REAL TIME CARRIER WAS NOT RECEIVED AT AOS. TRANSMITTER "C" CARRIER WAS RECEIVED FOR A SHORT TIME AND THEN DISAPPEARED. PROBLEM WAS REPEATED ON DOY 020. SIGNALS RETURNED TO NORMAL ON NEXT ORBIT AFTER EACH OCCURRENCE. IT IS BELIEVED THAT CABIN PRESSURE VENTING THROUGH THE CABIN PRESSURE RELIEF VALVE UNDER THE THERMAL CURTIN DUE TO M509 PRESSURE VENTING WAS SUFFICIENT TO CAUSE QUADRIPLEXER CORONA.	NONE. TWO-WATT TRANSMITTER PROVIDED REAL TIME DATA DURING PROBLEM OCCURRENCE. CREW CLOSED PANEL 391 RELIEF VALVE INADVERTENTLY LEFT OPEN.	NONE
NOISE INTERFERENCE OF APPROXIMATELY 6 HZ ON AUDIO SYSTEM CHANNEL "B" (SL-4)	ON DOY 019, THE CREW REPORTED A 6 HZ NOISE ON THE CHANNEL "B" EARPHONE LINE AUDIO. THESE SYMPTOMS INDICATED THAT THE PROBLEM WAS IN THE CHANNEL "B" AUDIO LOAD COMPENSATOR (ALC) #1 SECONDARY EARPHONE AMPLIFIER.	WORK-AROUND PROCEDURE IMPLEMENTED ON DOY 22, I.E. PULLED CIRCUIT BREAKER DURING SLEEP PERIODS.	NONE
	ON DOY 30 CREW INSTALLED EMERG/TAPE RECORDER VOICE CABLE ASSY LAUNCHED ON SL-4; CABLE REMOVED DOY 32 DUE TO LOW AUDIO LEVEL OF VOICE RECORDING.	CREW ADVISED TO USE HIGHER VOICE LEVEL TO OBTAIN SATISFACTORY RECORDED VOICE LEVELS.	

APPENDIX F

END-OF-MISSION STATUS

THIS APPENDIX PRESENTS A DETAILED END-OF-MISSION STATUS OF ALL AIRLOCK SYSTEMS.

AIRLOCK END-OF-MISSION SYSTEM STATUS

SYSTEM/OPERATIONAL FUNCTION	SUBSYSTEM/COMPONENT	EOM STATUS
1. STRUCTURAL/MECHANICAL		
• MAINTAIN PRESSURE INTEGRITY.	AIRLOCK MODULE (STS, TUNNEL AND FLEX TUNNEL EXTENSION)	LEAKAGE RATE WELL WITHIN SYSTEM ALLOWABLE; NO INCREASE IN LEAKAGE RATE NOTED DURING MISSION.
	HATCH SEALS	SEALS IN EXCELLENT CONDITION; NO DEGRADATION IN SEALING CAPABILITY.
• PROVIDE RIGIDITY AND DAMPING CHARACTERISTICS REQUIRED TO MAINTAIN EXPERIMENTS AND ATM POINTING ACCURACIES.	DEPLOYMENT ASSEMBLY (RIGIDIZING AND LATCHING MECHANISM)	BOTH MECHANISMS FULLY LATCHED; NO EFFECT ON EXPERIMENT OR ATM OPERATION.
• PROVIDE AN EVA CAPABILITY.	EVA AND INTERNAL HATCH MECHANISMS	OPERATION OF ALL HATCH MECHANISMS WAS SMOOTH WITH NO REPORTED OPENING OR CLOSING PROBLEMS.
• PROVIDE A MOVABLE PROTECTIVE COVER FOR STS WINDOWS.	EXTERNAL MOVABLE COVER ASSEMBLY	WINDOW COVER MECHANISM OPERATING AS EXPECTED WITH NO SIGNIFICANT CHANGE IN CRANK LOADS.
2. THERMAL CONTROL SYSTEM (TCS)		
• PROVIDE CLUSTER ATMOSPHERIC COOLING, AM EQUIPMENT COOLING, EVA SUIT COOLING AND ATM C&D/EREP COOLING BY CIRCULATING COOLANT FLUID.	ACTIVE COOLANT SYSTEM - PRIMARY AND SECONDARY LOOPS	BOTH COOLANT SYSTEMS WORKING NORMALLY • PRIMARY SYSTEM SUCCESSFULLY RESERVICED DURING SL-4. • SECONDARY SYSTEM RESERVOIR LOW LIGHT ACTIVATED ON LAST DAY OF SL-4 - RESERVICE KIT AVAILABLE. • ALL SIX PUMP OPERATING NORMALLY - ONE OF SIX INVERTERS INOPERATIVE.
• PROVIDE A HEAT SINK FOR EXCESS HEAT DISPOSAL.	ACTIVE COOLANT SYSTEM - RADIATOR AND THERMAL CAPACITOR	RADIATOR/THERMAL CAPACITOR WORKING NORMALLY HEAT REJECTION CAPABILITY EXCEEDED REQUIREMENT. DATA INDICATED SLIGHT INCREASE IN ABSORPTIVITY.

AIRLOCK END-OF-MISSION SYSTEM STATUS (CONTINUED)

SYSTEM/OPERATIONAL FUNCTION	SUBSYSTEM/COMPONENT	EOM STATUS
• PROVIDE CONTROLLED COOLANT TEMPERATURES FOR SELECTED COMPONENT GROUPS.	ACTIVE COOLANT SYSTEM - THERMAL CONTROL VALVES (TCV)	ALL TCV'S OPERATING NORMALLY.
• MAINTAIN THE TEMPERATURE OF ELECTRICAL POWER CONDITIONING	ACTIVE COOLING SYSTEM - SUIT/BATTERY MODULE, BATTERY HEAT EXCHANGER	SYSTEM WORKING NORMALLY; TEMPERATURE OF COOLANT ENTERING THE BATTERY MODULE HAD BEEN MAINTAINED AT APPROXIMATELY 40°F EXCEPT DURING HIGH BETA ANGLES.
• PROVIDE ACTIVE COOLANT SYSTEM ACROSS MDA/STS I/F TO COOL ATM C&D/EREP EQUIPMENT.	ATM C&D/EREP COOLING SYSTEM	SYSTEM PERFORMANCE ADEQUATE • FLUCTUATION OF FLOW APPARENTLY CAUSED BY GAS IN SYSTEM - FULL FLOW RESTORED BY PERIODIC USE OF SPARE LIQUID/GAS SEPARATOR. • ALL THREE PUMPS FULLY OPERATIONAL.
• REMOVE HEAT FROM ATM C&D/EREP COOLING SYSTEM.	ATM C&D/EREP COOLING SYSTEM - HEAT EXCHANGER	NORMAL PERFORMANCE; OPERATING WITHIN REQUIRED TEMPERATURE RANGE.
• PROVIDE THERMAL CONTROL FOR FAS INSTALLED EQUIPMENT.	THERMAL COATINGS - FAS INTERIOR/EXTERIOR COATINGS, TUNNEL WALL AND STS BULKHEAD EXTERIOR COATINGS	PERFORMANCE NORMAL - ALL TEMPERATURE READINGS AS EXPECTED - NO SIGNIFICANT DEGRADATION DURING THE MISSION.
	THERMAL AND METEOROID CURTAINS	PERFORMANCE NORMAL - ALL TEMPERATURES AS EXPECTED.
• PROTECT WATER SYSTEMS FROM FREEZING.	MICROFOIL INSULATION (EXTERNAL)	WORKING NORMALLY - COLDER THAN DESIGN CONDITIONS OCCURRED EARLY IN MISSION WITH NO APPARENT PROBLEMS FROM SYSTEM FREEZING.
• PREVENT CONDENSATION ON WATER AND COOLANT LINES.	MOSITE INSULATION (INTERNAL)	WORKING NORMALLY - NO CONDENSATION PROBLEM REPORTED.

AIRLOCK END-OF-MISSION SYSTEM STATUS (CONTINUED)

SYSTEM/OPERATIONAL FUNCTION	SUBSYSTEM/COMPONENT	EOM STATUS
• MAINTAIN AM COMPARTMENT WALL TEMPERATURE ABOVE MINIMUM SPECIFIED LIMIT.	AM WALL HEATERS - HEATING ELEMENT, THERMOSTATS	WORKING NORMALLY - TEMPERATURES WERE MAINTAINED WITHIN SPECIFIED LIMITS THROUGHOUT THE MISSION.
• MAINTAIN MOLECULAR SIEVE EXHAUST DUCT TEMPERATURE ABOVE WATER FREEZING TEMPERATURE.	MOLECULAR SIEVE EXHAUST DUCT HEATERS - HEATING ELEMENT, THERMOSTATS	WORKING NORMALLY.
3. ENVIRONMENTAL CONTROL SYSTEM (ECS)		
• PROVIDE GAS STORAGE SYSTEM TO SUPPORT PRESSURIZATION REQUIREMENTS.	GAS STORAGE SYSTEM - O_2/N_2 TANKS	NORMAL PERFORMANCE - NO DETECTABLE LEAKAGE; O_2 REMAINING 2609 LBS; N_2 REMAINING 609 LBS.
• AUTOMATICALLY MAINTAIN CLUSTER ATMOSPHERIC PRESSURE TO 5 ± 0.2 PSIA WITH PPO_2 OF 3.6 ± 0.3 PSIA.	ATMOSPHERE CONTROL SYSTEM - TWO GAS CONTROL SYSTEM	ALL REGULATORS PERFORMING NORMALLY - PROBLEM WITH 150 PSI N_2 REGULATOR CLEARED SELF DURING SL-4. PPO_2 SENSOR WORKING CORRECTLY.
• LIMIT THE MAXIMUM ATMOSPHERIC PRESSURE TO 6.0 PSIG AFTER ACTIVATION.	CABIN PRESSURE RELIEF VALVES	FUNCTIONING NORMALLY.
• PROVIDE CAPABILITY TO PRESSURIZE/DEPRESSURIZE CLUSTER, INCLUDING LOCK COMPARTMENT.	GAS SYSTEM - VENTS	FUNCTIONING NORMALLY - REMOVABLE SCREEN FOR AIRLOCK DEPRESS VALVE FLOWN ON SL-3; ALLOWS QUICK REMOVAL OF ICE BUILDUP.
• PROVIDE CAPABILITY TO MAINTAIN ATMOSPHERIC PRESSURE BETWEEN 0.5 PSI AND 1.5 PSI DURING ORBITAL STORAGE.	GAS SYSTEM - REGULATORS, CONTROL VALVES	FUNCTIONING NORMALLY.

AIRLOCK END-OF-MISSION SYSTEM STATUS (CONTINUED)

SYSTEM/OPERATIONAL FUNCTION	SUBSYSTEM/COMPONENT	EOM STATUS
• CONTROL HUMIDITY LEVEL IN CLUSTER.	ATMOSPHERIC CONTROL SYSTEM - COOLANT SYSTEM, CONDENSING HEAT EXCHANGER, WATER SEPARATOR ASSEMBLY	FUNCTIONING NORMALLY - ALL CONDENSING HEAT EXCHANGERS FULLY OPERATIONAL. SPARE WATER SEPARATOR ASSEMBLIES AVAILABLE.
• DISPOSE OF CONDENSATE BY TRANSFER TO OWS HOLDING TANK OR VENTING OVERBOARD.	CONDENSATE SYSTEM - LINES, VALVES, TANKS, QUICK DISCONNECTS	PERFORMANCE ADEQUATE - OCCASIONALLY FAILED TO HOLD VACUUM - CORRECTED BY QD RECONNECTION OR CAPPING. O-RING LUBRICATION PROCEDURE ON-BOARD
• REMOVE CARBON DIOXIDE AND ODORS FROM CLUSTER ATMOSPHERE.	ATMOSPHERIC CONTROL SYSTEM - MOLECULAR SIEVE SYSTEM, $PPCO_2$ DETECTORS	BOTH MOLECULAR SIEVE SYSTEMS ARE FULLY OPERATIONAL. JUMPER CABLE FLOWN ON SL-4 TO ALLOW POWERING OF SIEVE B FAN FROM SIEVE A INVERTER. $PPCO_2$ DETECTOR PERFORMANCE IS ADEQUATE - ALL SENSORS RESPOND TO CO_2 LEVEL CHANGE AND MOLE SIEVE A SENSOR WAS PERFORMING NORMALLY - PERIODIC CHECKS MADE WITH M171.
• PROVIDE ATMOSPHERIC TEMPERATURE CONTROL (60° TO 90°F).	ATMOSPHERIC CONTROL SYSTEM - COOLANT SYSTEM, HEAT EXCHANGERS, FANS, DUCTS	SYSTEM WORKING NORMALLY.
• PROVIDE ATMOSPHERIC CIRCULATION THROUGHOUT CLUSTER.	ATMOSPHERIC CONTROL SYSTEM - COOLANT SYSTEM, HEAT EXCHANGERS, FANS, DUCTS	SYSTEM PERFORMANCE SATISFACTORY - PERIODIC VACUUMING OF OWS HEAT EXCHANGERS RESTORED FULL FLOW.
• PROVIDE INFLIGHT SERVICING OF WATER SEPARATOR PLATES.	INFLIGHT WATERING SYSTEM - TANKS, HOSES, VALVES, QUICK DISCONNECTS	WORKING NORMALLY.

AIRLOCK END-OF-MISSION SYSTEM STATUS (CONTINUED)

SYSTEM/OPERATIONAL FUNCTION	SUBSYSTEM/COMPONENT	EOM STATUS
4. EVA/IVA SUIT SYSTEM		
• SUPPLY O_2 TO THREE UMBILICALS TO PROVIDE EVA/IVA SUIT ATMOSPHERE CONTROL TEMPERATURE AND PRESSURE.	EVA/IVA O_2 SUPPLY - REGULATORS, LINES VALVES, QUICK DISCONNECTS, HEAT EXCHANGER	SYSTEM WORKING NORMALLY. ADEQUATE COOLING PROVIDED ON ONE EVA BY O_2 FLOW ONLY.
• SUPPLY WATER COOLING SYSTEM FOR EVA/IVA SUIT TEMPERATURE - PROVIDE HEATING OR COOLING AS REQUIRED.	SUS COOLING LOOPS - PUMPS, LINES, VALVES, HEAT EXCHANGER	BOTH SUS LOOPS FULLY OPERATIONAL - ALL FOUR PUMPS OPERATIONAL. SUS #1 RESERVOIR DEPLETED DURING FINAL EVA.
• PROVIDE CAPABILITY TO CONNECT UMBILICALS IN STS OR LOCK COMPARTMENT.	EVA CONTROL PANELS, IVA CONTROL PANEL, DISCONNECT	ALL EVA/IVA CONTROL PANELS FULLY OPERATIONAL.
• PROVIDE LIQUID/GAS SEPARATOR TO CONTROL GAS IN WATER LOOP.	SUS COOLING LOOPS	LIQUID/GAS SEPARATOR FUNCTIONING NORMALLY • ONE SPARE GAS SEPARATOR ASSEMBLY AVAILABLE. • ONE SPARE GAS SEPARATOR ASSEMBLY EFFECTIVELY USED TO REMOVE GAS FROM ATM C&D LOOP.
• PROVIDE CAPABILITY TO STOW TWO UMBILICALS.	UMBILICAL STORAGE CONTAINERS	FUNCTIONING AS PLANNED.
• PROVIDE FOR SUS LOOP RESERVICING	INFLIGHT SERVICING SYSTEM - HOSES, VALVES, QUICK DISCONNECTS, DEIONIZER	SYSTEM FULLY OPERABLE • SUS LOOP SATISFACTORILY SERVICED DURING MISSION. • SUS LOOP #1 REQUIRES RESERVICING.

AIRLOCK END-OF-MISSION SYSTEM STATUS (CONTINUED)

SYSTEM/OPERATIONAL FUNCTION	SUBSYSTEM/COMPONENT	EOM STATUS
5. ELECTRICAL POWER SYSTEM		
● RECEIVE AND CONDITION SOLAR ARRAY POWER FROM THE OWS ARRAY. ● PROVIDE FOR DISTRIBUTION OF POWER TO SYSTEM LOADS AND TO BATTERY CHARGING. ● PROVIDE FOR CONTROL OF POWER TRANSFER BETWEEN THE AM, ATM, AND CSM.	BATTERY CHARGERS, BATTERIES, VOLTAGE REGULATORS, RELAYS, CIRCUIT BREAKERS, SWITCHES, POTENTIOMETERS, INSTRUMENTATION, DCS CONTROL AND WIRING SYSTEM.	ELECTRICAL POWER SYSTEM FULLY OPERATIONAL ● NO REPORTED ANOMALIES OR SUSPECTED MALFUNCTIONS. ● ALL BATTERIES FULLY OPERATIONAL 1) APPROXIMATELY 3800 BATTERY CYCLES THROUGH SL-4. 2) DEGRADATION RATE LOWER THAN PREDICTED.
6. SEQUENTIAL SYSTEM		
● PROVIDE THE ELECTRICAL CONTROL FOR THE LAUNCH SEQUENCE OF EVENTS.	SEQUENTIAL SYSTEM COMPONENTS	ALL FUNCTIONS SUCCESSFULLY COMPLETED ON SL-1/2, SYSTEM DEACTIVATED AND SECURED AS PLANNED.
7. INSTRUMENTATION SYSTEM		
● ACQUIRE, MULTIPLEX AND ENCODE DATA FROM THE AM, OWS AND MDA AND PROVIDE IT: 1) VIA TELEMETRY, FOR REAL TIME COVERAGE 2) VIA TAPE RECORDING, FOR CONTINUOUS COVERAGE 3) VIA PANEL DISPLAYS, FOR CREWMEN	INSTRUMENTATION SYSTEM INCLUDING: ● PROGRAMMERS (2) ● MULTIPLEXERS (13 IN AM; 12 IN OWS) ● INTERFACE BOX ● DC-DC CONVERTERS (5) ● TAPE RECORDERS 3 ACTIVE 4 SPARE 2 LAUNCHED ON SL-3 ● SENSORS AND SIGNAL CONDITIONERS ● PORTABLE TIMERS (4)	SYSTEM OPERATING NORMALLY EXCEPT: ● 79 PARAMETERS OUT OF APPROXIMATELY 1400 WERE KNOWN TO BE PARTIALLY OR TOTALLY DEGRADED: 1) 8 CHANNELS IN EACH AM LOW LEVEL MULTIPLEXER WERE NOISY 2) 3 FLOWMETER SENSORS FAILED 3) ONE SIGNAL CONDITIONER DEGRADED SYSTEM FULLY CAPABLE OF SUPPORTING ALL MISSION OBJECTIVES. ALL REDUNDANT COMPONENTS FULLY OPERATIONAL. ● TAPE RECORDER STATUS: 3 INSTALLED AND OPERATIONAL 3 AVAILABLE AS SPARES

AIRLOCK END-OF-MISSION SYSTEM STATUS (CONTINUED)

SYSTEM/OPERATIONAL FUNCTION	SUBSYSTEM/COMPONENT	EOM STATUS
		2 REPAIRABLE USING REPAIR KIT AND PROCEDURES LAUNCHED ON SL-4 1 FAILED
8. COMMUNICATION SYSTEM		
• PROVIDE ELAPSED TIME TO TELEMETRY AND TO CREW DISPLAY PANEL; PROVIDE TIMED RESET OF COMMAND FUNCTIONS; PROVIDE TIMED AUTOMATIC SWITCHOVER OF DCS.	TIME REFERENCE SYSTEM: • ELECTRONIC TIMERS (3) • TIME CORRELATION BUFFERS (2) • DIGITAL DISPLAY UNIT (2 ACTIVE, 1 SPARE) • DIGITAL CLOCK	ENTIRE SYSTEM FUNCTIONING NORMALLY: • ALL REDUNDANT UNITS FUNCTIONING. • DDU SPARE UNIT NOT USED.
• DETERMINE RANGE AND RANGE RATE DURING RENDEZVOUS; PROVIDE MEANS FOR VISUAL LOCATION OF SWS DURING RENDEZVOUS; PROVIDE ORIENTATION INFORMATION DURING DOCKING	RENDEZVOUS AND DOCKING SUBSYSTEM: • VHF TRANSCEIVER • RANGING TONE TRANSFER ASSEMBLY • TRACKING LIGHTS (4) • DOCKING LIGHTS (8)	ENTIRE SYSTEM FUNCTIONING NORMALLY: • REDUNDANT TRACKING LIGHTS WERE NEVER OPERATED.
• PROVIDE TRANSMISSION OF REAL TIME AND DELAYED TIME TELEMETRY AND DELAYED TIME VOICE; PROVIDE FOR RECEPTION OF COMMAND DATA; PROVIDE SELECTION BETWEEN ANTENNAS TO OPTIMIZE TRANSMISSION AND RECEPTION.	DATA TRANSMISSION AND ANTENNA SUBSYSTEM: • 2-WATT TRANSMITTER • 10-WATT TRANSMITTERS (3) • DISCONE ANTENNAS (2) o STUB ANTENNAS (2) o QUADRIPLEXER	ENTIRE SUBSYSTEM FUNCTIONING NORMALLY EXCEPT FOR FAILED 10-WATT TRANSMITTER • 3 TRANSMITTER CONFIGURATION MAINTAINED WITH 2-WATT TRANSMITTER. • PCM S-BAND CABLE LAUNCHED ON SL-4 WOULD PROVIDE CAPABILITY TO DOWNLINK AM RECORDED DATA VIA CSM S-BAND SYSTEM - NOT INSTALLED.

AIRLOCK END-OF-MISSION SYSTEM STATUS (CONTINUED)

SYSTEM/OPERATIONAL FUNCTION	SUBSYSTEM/COMPONENT	EOM STATUS
• PROVIDE COMMAND CAPABILITY TO. 1) PROVIDE GROUND CONTROL OF ONBOARD SWITCHING FUNCTIONS, 2) UPDATE THE TIME REFERENCE SUBSYSTEM AND, 3) SEND UPDATE MESSAGES TO THE TELEPRINTER.	DIGITAL COMMAND SUBSYSTEM: • RECEIVER/DECODERS (2) • RELAY MODULES (4) • COMMAND RELAY DRIVER UNIT	ENTIRE SUBSYSTEM FUNCTIONING NORMALLY EXCEPT COMMAND NO. 19.3 (EXP 2/DATA 2 TAPE RECORDER FAST FORWARD) WHICH WAS DETERMINED UNUSABLE BECAUSE OF A RESET PROBLEM. • BOTH PRIMARY AND SECONDARY SYSTEMS FUNCTIONAL AT EOM.
• PROVIDE HARD COPY UPLINK MESSAGES TO CREW.	TELEPRINTER SUBSYSTEM • TELEPRINTERS (1 ACTIVE, 1 SPARE) • INTERFACE ELECTRONICS UNIT • SPARE CARTRIDGE AND SPOOL • PAPER (156 ROLLS)	SUBSYSTEM FUNCTIONING NORMALLY • REPAIR KIT LAUNCHED ON SL-4 TO REPAIR FAILED DRIVE ROLLER ON SPARE TELEPRINTER. • OVER 100 ROLLS OF PAPER AVAILABLE.
• PROVIDE REAL TIME VOICE COMMUNICATION BETWEEN CREW MEMBERS AND BETWEEN CREW AND THE GROUND; PROVIDE RECORDING OF CREW VOICE; PROVIDE TWO CHANNEL OPERATION.	AUDIO SUBSYSTEM • SPEAKER INTERCOM ASSEMBLIES (13 ACTIVE, 2 SPARE) • AUDIO LOAD COMPENSATORS (2) • CREWMAN COMMUNICATION UMBILICALS (3) • LIGHTWEIGHT CCU'S (8) • LCCU CONTROL HEADS (4)	ENTIRE SYSTEM FUNCTIONING NORMALLY EXCEPT: • VOICE RECORD CAPABILITY AVAILABLE FROM CHANNEL A ONLY. • EARPHONE LINE DEGRADED ON CHANNEL B. • EMERGENCY/TAPE RECORDER VOICE CABLE PROVIDED MICROPHONE LINE AUDIO FOR TAPE RECORDING OR EMERGENCY DOWNLINK, BYPASSING FAILED ALC; LAUNCHED ON SL-4; INSTALLED, THEN REMOVED. • BOTH SPARE SIA'S USED.

AIRLOCK END-OF-MISSION SYSTEM STATUS (CONTINUED)

SYSTEM/OPERATIONAL FUNCTION	SUBSYSTEM/COMPONENT	EOM STATUS
9. CAUTION AND WARNING • PROVIDE THE CREW WITH VISUAL DISPLAYS AND AUDIBLE TONES WHEN SPECIFIED CLUSTER PARAMETERS REACH OUT-OF-TOLERANCE CONDITIONS.	C&W SUBSYSTEM, EMERGENCY SUBSYSTEM: • C&W UNIT • HLAA • KLAXON ASSYS (2) • C&W SIGNAL CONDITIONING PACKAGES (2) • C&W DISPLAY CONVERTERS (2) • CONTROL PANELS • FSCP'S (12 ACTIVE, 2 SPARE) • FSA'S (22 ACTIVE, 6 SPARE)	SYSTEM FULLY OPERATIONAL EXCEPT FOR ONE EVA PARAMETER - EVA LCG-1 PUMP DELTA P (K931): • REDUNDANT COMPONENTS ALL OPERATIONAL. • ONE SPARE FIRE SENSOR CONTROL PANEL AVAILABLE, REPLACED UNIT AVAILABLE AS SPARE FOR LOCATIONS REQUIRING ONLY SIDE 1.
10. CREW SYSTEMS • PROVIDE LIGHTING FOR EVA	DA FLOODLIGHTS EVA HATCH LIGHTS	LIGHTS FUNCTIONING NORMALLY
• PROVIDE INTERNAL LIGHTING	STS LIGHTS TUNNEL LIGHTS STATUS LIGHTS	ALL LIGHTS FULLY OPERATIONAL • NO REPORTED ANOMALIES. • APPROXIMATELY 100 SPARE BULBS AVAILABLE.
• PROVIDE DISPLAYS FOR CREW USE.	PANELS	ALL PANELS FULLY OPERATIONAL.
• PROVIDE CAPABILITY TO PERFORM EVA.	EVA HATCH EVA EQUIPMENT	ALL EQUIPMENT AND SYSTEMS OPERATING NORMALLY. • HATCH LOCKING PIN OPENED, SAWTOOTH CATCH RETRACTED AND LOCK DEPRESS VALVE UNCAPPED SO THAT EVA HATCH ENTRY MAY BE MADE EXTERNALLY IN FUTURE REVISIT.

AIRLOCK END-OF-MISSION SYSTEM STATUS (CONTINUED)

SYSTEM/OPERATIONAL FUNCTION	SUBSYSTEM/COMPONENT	EOM STATUS
• PROVIDE FOR ATM FILM TRANSFER.	FILM TRANSFER BOOMS GFE CLOTHESLINE	BOTH BOOMS OPERATED NORMALLY: • VC BOOM LEFT IN EXTENDED POSITION. • SPARE BOOM UNUSED. BOTH CLOTHESLINE DEPLOYED AND OPERATED SATISFACTORILY.
11. EXPERIMENTS		
• PROVIDE HIGH PRESSURE N_2 TO M509/T020 PROPELLANT SUPPLY SUBSYSTEM (PSS)	M509 RECHARGE STATION	RECHARGE STATION IS FULLY OPERATIONAL-- N_2 SUPPLY PRESSURE IS APPROXIMATELY: • 670 PSI IN TANKS 3, 4, 5 AND 6. • 1850 PSI IN TANKS 1 AND 2.
• PROVIDE SUPPORT FOR D024 THERMAL CONTROL MATERIALS	D024 MODULE AND SUPPORT STRUCTURE	D024 MODULE IN PLACE; ALL SNAPS AND RELEASE PINS FULLY OPERATIONAL: ALL SAMPLES AND CONTAINERS REMOVED.
• PROVIDE MOUNTING SUPPORT FOR S230 FOIL SAMPLES	S230 MAGNETOSHPHERE PARTICLE COLLECTOR MOUNTING	HOLDER SPOOLS REMAIN MOUNTED ON DA TRUSS. ALL FOIL SAMPLES REMOVED.
• PROVIDE ELECTRICAL POWER AND MOUNTING SUPPORT FOR S193	S193 SUPPORT BRACKETS, ELECTRICAL WIRING	S193 FULLY OPERATIONAL - MOUNTED ON DA.
• PROVIDE MOUNTING SUPPORT FOR RADIO NOISE BURST MONITOR (RNBA) ANTENNA	RNBA SUPPORT STRUCTURE, COAX CABLE	RNBA FULLY OPERATIONAL - ANTENNA IN PLACE ON AM TRUSS #4.

APPENDIX G

ACRONYMS AND ABBREVIATIONS

THE FOLLOWING LIST INCLUDES THOSE ACRONYMS AND ABBREVIATIONS CONSIDERED APPROPRIATE TO THE AIRLOCK/SKYLAB PROGRAM. OBVIOUS STANDARD ABBREVIATIONS ARE NOT INCLUDED.

ACRONYMS AND ABBREVIATIONS

AAP	Apollo Applications Program
AATR	Apollo Applications Test Requirements
ABCL	As-Build Configuration List
ACE	Automatic Checkout Equipment
ACQ	Acquisition
ACS	Attitude Control System
A/D	Analog To Digital
AGE	Aerospace Ground Equipment
AHM	Ampere/Hour Meter
ALC	Audio Load Compensator
ALSA	Astronaut Life Support Assembly
AM	Airlock Module
AMS	Airlock Module Station
APCS	Attitude Pointing and Control System
AR	Anomaly Report
ASC II	American Standard Code For Information Interchange
ATLO	Acceptance Test and Launch Operations
ATM	Apollo Telescope Mount
ATP	Acceptance Test Procedure
BCD	Binary Coded Decimal
BIC	Basic Interlace Controller
BILCA	Backup Inverter Lights Control Assembly
B/L	Bilevel
BLP	Bilevel Pulse
C/B	Circuit Breaker
CBRM	Charger-Battery-Regulator Module (ATM)
CCB	Change Control Board
CCC	Command Control Console
CCP	Contract Change Proposal
CCS	Command Communications System
CCSR	Crew Compartment Stowage Review
CCU	Crewman Communication Umbilical
C&D	Control and Display
CDDT	Countdown Demonstration Test
CDF	Confined Detonating Fuse
CDR	Critical Design Review
CEI	Contract End Item
CFE	Contractor Furnished Equipment
CIL	Critical Item List
CIWG	Change Integration Working Group
CLNT	Coolant
CLT	Cargo Lift Trailer
CKT BD	Circuit Board
CM	Command Module
CMD	Command
CMG	Control Moment Gyro
COFW	Certification of Flight Worthiness
COMM	Communications
CONV	Converter
CP	Control Procedure
C/P	Cold Plate

CPPI	Coolant Pump Power Inverters
CR	Change Request
CRDU	Command Relay Drive Unit
CRS	Cluster Requirements Specification
CSDR	Cluster System Design Review
CSM	Command and Service Module
C&W	Caution and Warning
CVPC	Control Valve Primary Coolant
CVSC	Control Valve Secondary Coolant
CWU	Caution and Warning Unit
C^2F^2	Crew Compartment Fit and Functional (Test)
DA	Deployment Assembly
DA-LO	Deployment Assembly Lower Unit
DAR	Deviation Approval Request
DAS	Data Acquisition System
DA-UP	Deployment Assembly Upper Unit
DCR	Design Certification Review
DCS	Digital Command System
DDA	Drawing Departure Authorization
DDU	Digital Display Unit
DOD	Depth of Discharge
DOY	Day Of Year
DR	Discrepancy Record
DT	Development Test
DTS	Data Transmission System
EBCDIC	Extended Binary Coded Decimal Interchange Code
EBW	Exploding Bridgewire
ECL	Engineering Configuration List
ECP	Engineering Change Proposal
ECR	Engineering Change Request
ECS	Environmental Control System
EDCR	Engineering Design Change Request
EDDU	EREP Diagnostic Downlink Unit
EDTA	Ethylene Diamine Tetra Acetic (Acid)
EJS	Engineering Job Sheet
E/M	Electrical Module
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EOP	Emergency Oxygen Pack
EPC	Experiment Pointing Control (System)
EPS	Electrical Power System
EREP	Earth Resource Experiment Package
ESE	Electrical Support Equipment
ET	Endurance Test
EVA	Extravehicular Activity
E&W	Emergency and Warning
FAS	Fixed Airlock Shroud
FMEA	Failure Mode and Effect Analysis
FRR	Flight Readiness Review
FRT	Flight Readiness Test
FSRT	Flight Systems Redundancy Test
FTB	Film Transfer Boom
FTC	Florida Test Center (MDAC)
GCE	Gemini Cape Engineering (A drawing system)

GFE	Government Furnished Equipment
GOSS	Ground Operations Support System
GSE	Ground Support Equipment
HOSC	Huntsville Operations Support Center
H/L	High Level
HX	Heat Exchanger
IB	Interface Box
I&C	Instrumentation and Communication
ICD	Interface Control Document
ICOM	Intercom
IDD	Interface Definition Document
IDR	Interim Discrepancy Record
IEU	Interface Electronics Unit
I/F	Interface
ILCA	Inverter Lights Control Assembly
I/O	Input/Output
IP&CL	Instrumentation Program and Components List
IRN	Interface Revision Notice
ISC	Current under Short Circuit
ITMG	Integrated Thermal Meteoroid Garment
IU	Instrumentation Unit
IVA	Intervehicular Activity
JOP	Joint Observation Program
LAH	Launch Axis Horizontal
LAV	Launch Axis Vertical
LC	Launch Complex
LCC	Launch Control Center
LCCU	Lightweight Crewman Communication Umbilical
LCG	Liquid-Cooled Garment
LDX	Long Distance Xerography
LEM	Lunar Exploration Module
L/L	Low Level
LM	Lunar Module
LM&SS	Lunar Mapping and Survey Station (Module)
LO	Launch Operations
LOM	Liftoff Monitor
LSB	Least Significant Bit
LSU	Life Support Umbilical
LUT	Launch Umbilical Tower
LV	Launch Vehicle
LVDC	Launch Vehicle Digital Computer
MCAIR	McDonnell Aircraft Company
MCE	Mercury Cape Engineering (A drawing system)
MDA	Multiple Docking Adapter
MDAC-E	McDonnell Douglas Astronautics Company - East
MDAC-W	McDonnell Douglas Astronautics Company - West
MDC	McDonnell Douglas Corporation
MDF	Mild Detonating Fuse
MEWG	Mission Evaluation Working Group
MF	Master Frame
MILA	Merritt Island Launch Area
ML	Mobile Launch

MMC	Martin Marietta Corporation
MMS	McDonnell Material Specifications
MODS	Mission Operations Design Support
MOLE	Molecular
MOPS	Mission Operations Planning System
MPS	Mission Preparation Sheet
MRD	Mission Requirements Document
MRR	Material Rejection Report
MSB	Most Significant Bit
MSFTP	Manned Space Flight Telemetry Decommutation Equipment
MSG	Mission Support Groups
MSOB	Manned Spacecraft Operations Building at KSC
MST	Modal Survey Test
MUX	Multiplexer
NBT	Neutral Buoyancy Trainer
NLT	Not Less Than
NMT	Not More Than
N_2	Nitrogen
NPV	Nonpropulsive Vent
NRZ	Nonreturn to Zero (PCM Code)
NSS	Noise Suppression System
NT	NASA Trainer
OA	Orbital Assembly
OAT	Overall Test
O&C	Operations and Checkout (Building) at KSC
OCV	Open Circuit Voltage
OSE	Operational Support Equipment
ORI	Operational Readiness Inspection
OSP	Operations Support Planning
OV	Orbital Vehicle
OWS	Orbital Workshop
PAT	Payload Assembly Test
PB	Process Bulletin
PCG	Power Conditioning Group
PCM	Pulse Code Modulation
PCN	Procedure Change Notice
PCU	Pressure Control Unit
PDR	Preliminary Design Review
PETN	Pentaerythrital Tetranitrate
PIA	Preinstallation Acceptance
PIRN	Preliminary Interface Revision Notice
PLV	Post Landing Ventilation
$PPCO_2$	Partial Pressure Carbon Dioxide
PPM	Parts Per Million
PPO_2	Partial Pressure Oxygen
PS	Payload Shroud
PS	Process Specification
PTT	Push/Press-To-Talk (Or Push/Press-To-Transmit)
PWO	Production Work Order
QA	Quality Assurance
QAP	Quality Assurance Procedure

QCMB	Quartz Crystal Micro Balance
QCM/CM	Quartz Crystal Microbalance Contamination Monitor
QD	Quick Disconnect
QLDS	Quick Look Data Station
RACS	Remote Automatic Calibration System
RE	Request for Estimate
RID	Review Item Discrepancy
RNBM	Radio Noise Burst Monitor
ROM	Rough Order of Magnitude
RS	Refrigeration System (OWS)
RSS	Refrigeration System Shield (OWS)
RTTA	Range Tone Transfer Assembly
RW	Reverse Wound
RZ	Return to Zero (PCM Code)
SA OAT	Swing Arm Over All Test
SAR	Spacecraft Acceptance Review
SAR	Special Action Request
SAS	Solar Array System
SAWS	Solar Array Wing Simulator
SCD	Source (Specification) Control Drawing
SCN	Specification Change Notice
SCPI	Suit Compressor Power Inverters
SDDS	Signal Data Demodulator System
SEDR	Service Engineering Department Report
SEVA	Standup EVA
SF	Subframe
SFP	Single Failure Point
SI	Solar Inertial
SIA	Speaker Intercom Assembly
SIT	Software Integration Test
SL	Skylab
SLA	Spacecraft Lunar Adapter
SL-1	Skylab 1 (Laboratory)
SL-2	Skylab 2 (Crew Vehicle 1)
SL-3	Skylab 3 (Crew Vehicle 2)
SL-4	Skylab 4 (Crew Vehicle 3)
SM	Service Module
SMER	Skylab Mission Evaluation Report
SMMD	Specimen Mass Measurement Device
S/O	Shutoff
SOC	State-of-Charge
SOCAR	Skylab Systems/Operations Compatibility Assessment Review
SOP	Supplemental Oxygen Package
SOS	Supplemental Oxygen System
SOW	Statement of Work
SPG	Single Point Ground
SPL	Sound Pressure Levels
SPS	Samples Per Second
SPT	Science Pilot
SSESM	Spent Stage Experiment Support Module
SSIE	Skylab Systems Integration Equipment
STA	Static Test Article
STDN	Spacecraft Tracking and Data Network
STS	Structure Transition Section
STU	Skylab Test Unit

SUS	Suit Umbilical System
SV	Space Vehicle
SWS	Saturn Workshop (PS/MDA/ATM/AM/OWS/IU/ATM, Deployment Assembly)
S-IB	Saturn First Stage
S-IB	Two Stage Saturn Launch Vehicle
S-IC	Saturn V First Stage
S-II	Saturn V Second Stage
S-IVB	Saturn IB Second Stage or Saturn V Third Stage
TACS	Thruster Attitude Control System (OWS)
TCB	Time Correlation Buffer
TCN	Test Change Notice
TCP	Test and Checkout Procedure
TCRSCD	Test Checkout Requirement Specification Criteria Document
TCS	Thermal Control System
TCV	Temperature Control Valve
TD	Technical Description
TDRS	Test Data Requirement Sheets
T_e	Elapsed Time
TM	Telemetry
TPS	Test Preparation Sheet
TR	Test Request
Tr	Time-To-Retrograde
TRS	Time Reference System
Tx	Time-To-Go Equipment Reset
UDB	Up Data Buffer
UMB	Umbilical
UV	Ultraviolet
U-1	Airlock Vehicle Unit 1
U-2	Airlock Vehicle Unit 2
VAB	Vehicle Assembly Building at KSC
VCO	Voltage Control Oscillator
VCS	Ventilation Control System
VDT	Vehicle Dynamics Test
VOC	Open Circuit Voltage
VS	Vehicle Station
VTR	Video Tape Recorder
WITS	West Integrated Test Stand (a test stand in the O&C Building at KSC)
WR	Waiver Request
Z-LV	Z Axis Along the Local Vertical
ΔP	Differential Pressure

APPENDIX H

REFERENCES

MCDONNELL DOUGLAS REPORTS

REPORT NO.	TITLE
E183	Quality Assurance for McDonnell Suppliers
E329	Voice, Telemetry and Command Technical Characteristics and Requirements for AM & MSFC Network
E503-1	Support Material List
E853	Airlock Electromagnetic Interference Control Plan
E854	Quality Assurance Provisions (Plan)
E855	Reliability Program Plan
E914	Airlock Acceptance Test Plan
E934	AM Facilities Plan
E935	Qualification Status Report
E946	Airlock Performance/Configuration Specification (CEI Specification) Flight Articles No. 1 and No. 2
F319	Airlock Equipment Environmental Design Requirements (Unmanned Launch)
F483-1	Airlock Module Structural Design Criteria and Loads
F630	Airlock Environmental Test Requirements
F639	Data Transmission System and Instrumentation Report
F673	Failure Mode and Effect Analysis
F680	Airlock Equipment Environmental Testing Requirements
F712	Airlock to S-IVB Environmental Interface Definition Document
F713	Airlock/MDA Environmental Control Interface Definition Document
F767	Development and Qualification Test Plan
F946	Airlock/Crew Systems Interface Definition Document
G075	Apollo Fuel Cell System Performance Specification
G079	AM Test Requirements for AM MDA
G193	S-IVB Solar Array Performance Specification
G219	Description of AM Structural Test Article
G229	QA and Configuration Control Plan AM, Structural Test Article
G241	GSE Development Plan, Airlock

MCDONNELL DOUGLAS REPORTS (CONTINUED)

REPORT NO.	TITLE
G308	Airlock Performance/Design Verification Report
G499	Airlock Equipment Acceptability Review
G671	Airlock Systems Safety Plan
G815	Airlock Reliability Model
H038	Airlock General Test Plan
E0041	Payload Shroud Development and Qualification Test Plan
E0042	Payload Shroud Acceptance Test Plan
E0047	Payload Shroud Detail CEI Specification
E0122	Airlock Test and Checkout Requirements Specification Criteria Document
E0195	Electrical Power System Specification
E0294	Coolant System Assurance Plan
E0321	Airlock Module Systems Malfunction Analysis
E0365	Critical Items List
E0469	Airlock Configuration Status Accounting Report

REPORT NO.	TITLE
E0471	Airlock Certification of Flightworthiness Plan
E0502	Skylab Telemetering and Recording Technical Manual
E0517	Verification of U-1 Launch and Ascent Structural Capabilities Based on Evaluation of STA-1 Static Test Results
E0545	Airlock Vibroacoustic Test Report
E0551	Selection, Training, and Certification of Personnel Involved in Altitude Chamber Testing
E0571	Airlock Mission Support Hardware Plan
E0578	Planned Work at KSC
E0613	Operational Readiness Inspection of the Facilities and Equipment Associated with the Manned Altitude Chamber Test of the AM/MDA
E0654	Effect of AM/MDA Mass Properties Change on AM Structural Capabilities
E0723	Airlock Mission Support Software Plan
E0765	FMEA for Manned Altitude Chamber Test of AM No. 2

MCDONNELL DOUGLAS REPORTS (CONTINUED)

REPORT NO.	TITLE
E0771	Experiment S230/AM (DA) Mech. Interface Definition Document
E0774	Airlock Hazards Identification Final Report
E0899	Skylab Airlock Module Final Technical Report
G0178	Payload Shroud Mass Property Status Report
G0368	AM PS Panel Structural Tests - Model DA-118
G1020	Transportation and Hardware Procedures for PS
G1260	Full-Scale Separation Test Plan Procedure Requirements
G4679A	Skylab Payload Shroud Final Technical Report
8617	Design and Testing Specification Project Gemini Aerospace Ground Equipment
	MISCELLANEOUS
No Number	Airlock Mission Operations Support Plan
AME 1219B	Payload Shroud Manufacturing Plan
ED-2002-395	Combined AM/MDA Structural Test Plan

REPORT NO.	TITLE
EPS-10	Airlock Logistics Plan
LS-005-003-2H	AM In-Flight Maintenance Task and Support Requirements Document
MH-72-0926	Transportation and Handling Plan for Skylab Flight Element Material Handling Procedure
MHP 72-0925-1	Material Handling Procedure
PS 315	System Maintenance Summary
PS 322	GSE Maintenance Summary
QAP 171-07-2000	Calibration of Tools
QAP 171-19-8008	Inspection System Requirements for McDonnell Subcontractors
QAP 171-19-8000	Outside Production Quality Assurance
QAP 171-19-8006	Outside QA Provisions for Suppliers of Spacecraft Components and Services
QAP 171-26-5501	Outside Production Quality Assurance
RA-159-H06	GSE Critical Items List
SP 10.229 AECD	System Test Inspection
233-M-501	Airlock Mass Properties Report

MCDONNELL DOUGLAS PROCESS SPECIFICATIONS AND STANDARDS

SPEC NO.	TITLE
DPS 25081	Preparation and Application of Sealant Materials
DPS 61103	Shroud Systems Packaging and Packing
DPS 64113	Payload Shroud Cleaning
MMS 602	Heat Transfer Fluid, Low Viscosity - 100° to 300°F
MMS 603	Oxygen, Liquid and Gas; for use in Servicing Spacecraft
MMS 604	Nitrogen, Liquid and Gas; for use in Servicing Spacecraft
MMS 605	Hydrogen, Liquid and Gas; for use in Servicing Model 113P
PS 12025	Ultrasonic Cleaning
PS 12300	Cleaning and Capping of Fluid Carrying Parts and Assemblies
PS 12302	Cleaning of Cryogenic, Hydraulic and Pneumatic System Lines and Components
PS 12304	Fluid Systems Components; Cleaning and Packaging of
PS 13618	Preparation and Application of Heat Transfer Compound
PS 17165	Teflon Wire Insulation; Etching to Provide a Bondable Surface
PS 17400	Wiring, Electrical, Spacecraft and Missiles/Installation of
PS 17410	Wiring, Electrical, Spacecraft and Missile; Fabrication of
PS 17410.2	Connectors, Electrical, Solder Type, Spacecraft and Missiles; Assembly of
PS 17410.4	Connectors, Electrical, Crimp Type, Spacecraft and Missiles; Assembly of
PS 20500	Fabrication and Housekeeping Policies Applicable to all Projects
PS 20501	Clean Room Class 6 and Class 10; Requirements for
PS 20502	Requirements for Class R Clean Room
PS 20513	Handling, Storage & Installation of Gaseous Systems
PS 20531	Coolant and Water System; Cleaning, Handling and Installation of

MCDONNELL DOUGLAS PROCESS SPECIFICATIONS AND STANDARDS

SPEC NO.	TITLE
PS 20590	Contamination in Fluids; Determination of
PS 21015	Safety Criteria for Pressure Tests
PS 21341	Wire, Electrical, for use on Spacecraft and Missiles; Receiving Inspection of
OP 101	Operational Ground Rules for Conduct of Acceptance Testing at MDAC-E, St. Louis
SP 6.502	Inspection System Requirements for McDonnell Subcontractors
SP 10.127	Selection of Procurement Sources
SP 10.229 AECD	System Test Inspection
SPB 715.1	Acceptance Test Requirements and Procedures
STD 5M1145	Wire, Electrical Extruded TFE-Flurocarbon Insulated, Silver coated Copper, 600 volts
STD 5M104	Cable - Electrical, TFE Fluorocarbon Insulated - Silver-coated Copper, 600 volt, Shielded and Unshielded
STM0391	Detonating Fuse (PETN)

SPEC NO.	TITLE
STM0577	Polyamide, Tubular, Woven Fabric
STM0598	Adhesive Silicone Paste, Low Outgassing
STP0402	Fabrication of Elastomeric Coated Tubing

MCDONNELL DOUGLAS DRAWINGS

DWG. NO.	TITLE
7865742	EWB Detonators
1C83657	Storage Procedures for End Items
1D15700-1	Payload Shroud Full-Scale Separation Test Article
40M35622	Airlock Power Allocation
40M35701	Skylab Caution and Warning Technical Manual
61A900000	Airlock Finish Specification
61B769004	Storage Battery, Nickel Cadmium
61B76005	DC Voltage Regulator
61B769006	Battery Charger
61C769018	Silicon Controlled Rectifier
61E000001	Major GSE Index
61J880002	Airlock Module - Instrumentation Program and Components List (IP&CL)
61T101000-303	General Assembly AM Static Test
61T101000-1	General Assembly AM Static Test
61T101001-1	General Assembly DA Dynamic Test
61T101002-1	General Assembly FAS Dynamic Test
MDC 06-0002-01	Supplier Packaging Instructions for Spacecraft and Missile Materials

MCDONNELL DOUGLAS VENDOR REPORTS

REPORT NO.	TITLE
QTP #714244	Qualification Test Procedure for Battery Charger Model EMBC 135
QTR #2639	Qualification Test Report for Battery Charger Model EMBC 135
ATP #714243	Acceptance Test Procedure for Battery Charger Model EMBC 135
ATP #180	Acceptance Test Procedure for Eagle Picher Battery SAR-8055-19
QTP - 107	Qualification Test Procedures for Eagle Picher Battery 61B769004
QTP #714282	Qualification Test Procedure for DCV Voltage Regulator Model EMVR 144
QTR #2586	Qualification Test Report for DC Voltage Regulator Model EMVR 144
ATP #714281	Acceptance Test Procedure for DC Voltage Regulator Model EMVR 144
GIR #2440	Gulton Industries Thermal Analysis Report for Modified Voltage Regulator

APPENDIX I

THIS APPENDIX IS AN

ABSTRACT FROM THE BARNEBEY-CHENEY

COMPANY CATALOG GIVING THE

ABSORPTION CAPACITY OF ACTIVATED CHARCOAL

CAPACITY OF ACTIVATED COCONUT SHELL CHARCOAL

FOR SPECIFIC VAPORS

The capacity index has the following meaning: -

4 - ACSC has high capacity for all materials in this category. One pound takes up about 20% to 50% of its own weight - average about 1/3 (33-1/3%). This category includes most of the odor causing substances.

3 - ACSC has a satisfactory capacity for all items in this category. These constitute good applications but the capacity is not as high as for category 4. In this range the ACSC takes up from about 10% to 25% of its weight - average about 1/6 (16.7%).

2 - Includes substances which are not highly adsorbed by ACSC but which might be taken up sufficiently to give good service under the particular conditions of operation. These require individual checking.

1 - Adsorption capacity is low for these materials. ACSC cannot be satisfactorily used to remove them under ordinary circumstances.

2 - Acetaldehyde
4 - Acetic Acid
4 - Acetic Anhydride
3 - Acetone
1 - Acetylene
3 - Acids
3 - Acrolein
4 - Acrylic Acid
4 - Acrylonitrile
4 - Adhesives
4 - Air Wick
4 - Alcohol
4 - Alcoholic beverages
2 - Amines
2 - Ammonia
4 - Amyl Acetate
4 - Amyl Alcohol
4 - Amyl Ether
3 - Animal odors
3 - Anesthetics
4 - Aniline
4 - Antiseptics
4 - Asphalt fumes
3 - Automobile exhaust
3 - Bacteria
4 - Bathroom smells
4 - Benzene
3 - Bleaching solutions
4 - Body odors
4 - Bromine
4 - Burned flesh
4 - Burned food
4 - Burning fat
3 - Butadiene
2 - Butane
4 - Butenone
4 - Butyl Acetate
4 - Butyl Alcohol
4 - Butyl Cellosolve
4 - Butyl Chloride
4 - Butyl Ether
2 - Butylene
2 - Butyne
3 - Butyraldehyde
4 - Butyric Acid
4 - Camphor
4 - Cancer Odor
4 - Caprylic Acid
4 - Carbolic Acid
3 - Carbon Bisulfide
1 - Carbon Dioxide
1 - Carbon Monoxide
4 - Carbon Tetrachloride
4 - Cellosolve
4 - Cellosolve Acetate
4 - Charred materials
4 - Cheese
3 - Chemicals
3 - Chlorine
4 - Chlorobenzene
4 - Chlorobutadiene
4 - Chloroform
4 - Chloro Nitropropane
4 - Chloropicrin
4 - Cigarette smoke
4 - Citrus and other fruits
4 - Cleaning compounds
3 - Coal smoke
3 - Combustion odors
4 - Cooking odors
3 - Corrosive gases
4 - Creosote
4 - Cresol
4 - Crotonaldehyde
4 - Cyclohexane
4 - Cyclohexanol
4 - Cyclohexanone
4 - Cyclohexene
4 - Dead animals
4 - Decane
4 - Decaying substances

Capacity of Activated Coconut Shell Charcoal
for specific vapors

4 - Decomposition odors
4 - Deodorants
4 - Detergents
4 - Dibromeothane
4 - Dichlorobenzene
3 - Dichlorodifluoromethane
4 - Dichloroethane
4 - Dichloroethylene
4 - Dichloroethyl Ether
3 - Dichloromonofluoromethane
4 - Dichloro-Nitroethane
4 - Dichloropropane
3 - Dichlorotetrafluoroethane
3 - Diesel fumes
3 - Diethyl Amine
4 - Diethyl Ketone
4 - Dimetnylaniline
4 - Dimethylsulfate
4 - Dioxane
4 - Dipropyl Ketone
4 - Disinfectants
4 - Embalming odors
1 - Ethane
3 - Ether
4 - Ethyl Acetate
4 - Ethyl Acrylate
4 - Ethyl Alcohol
3 - Ethyl Amine
4 - Ethyl Benzene
3 - Ethyl Bromide
3 - Ethyl Chloride
3 - Ethyl Ether
3 - Ethyl Formate
4 - Ethyl Mercaptan
4 - Ethyl Silicate
1 - Ethylene
4 - Ethylene Chlorhydrin
4 - Ethylene Dichloride
3 - Ethylene Oxide
4 - Essential oils
4 - Eucalyptole
3 - Exhaust fumes
4 - Femal odors
4 - Fertilizer
3 - Film processing odors
4 - Fish odors
4 - Floral scents
3 - Fluorotrichloromethane
4 - Food aromas

2 - Formaldehyde
3 - Formic Acid
3 - Freon
2 - Fuel gases
3 - Fumes
4 - Gangrene
4 - Garlic
4 - Gasoline
4 - Heptane
4 - Heptylene
3 - Hexane
3 - Hexylene
3 - Hexyne
4 - Hospital Odors
4 - Household smells
1 - Hydrogen
2 - Hydrogen Bromide
2 - Hydrogen Chloride
3 - Hydrogen Cyanide
2 - Hydrogen Fluoride
3 - Hydrogen Iodide
2 - Selenide
3 - Hydrogen Sulfide
4 - Incense
4 - Indole
3 - Inorganic chemicals
3 - Incomplete combustion
3 - Industrial wastes
4 - Iodine
4 - Iodoform
4 - Irritants
4 - Isophorone
3 - Isoprene
4 - Isopropyl Acetate
4 - Isopropyl Alcohol
4 - Isopropyl Ether
4 - Kerosene
4 - Kitchen odors
4 - Lactic Acid
4 - Lingering Odors
4 - Liquid Fuels
4 - Liquor Odors
4 - Lubricating oils and greases
4 - Lysol
4 - Masking agents
4 - Medicinal odors
4 - Melons
4 - Menthol

4 - Mercaptans
4 - Mesityl Oxide
1 - Methane
3 - Methyl Acetate
4 - Methyl Acrylate
3 - Methyl Alcohol
3 - Methyl Bromide
4 - Methyl Butyl Ketone
4 - Methyl Cellosolve
4 - Methyl Cellosolve Acetate
3 - Methyl Chloride
4 - Methyl Chloroform
3 - Methyl Ether
4 - Methyl Ethyl Ketone
3 - Methyl Formate
4 - Methyl Isobutyl Ketone
3 - Methyl Formate
4 - Methyl Isobutyl Ketone
4 - Methyl Mercaptan
3 - Methylal
4 - Methlcyclohexane
4 - Methylcyclohexanol
4 - Methylcyclohexanone
4 - Methylene Chloride
3 - Mildew
4 - Mixed odors
3 - Mold
4 - Monochlorobenzene
3 - Monofluorotrichloromethane
4 - Moth Balls
4 - Naphta (Coal tar)
4 - Naphtha (Petroleum)
4 - Naphthalene
4 - Nicotine
3 - Nitroc Acid
4 - Nitro Benzenes
4 - Nitroethane
2 - Nitrogen Dioxide
4 - Nitroglycerine
4 - Nitromethane
4 - Nitropropane
4 - Nitrotoluene
4 - Nonane
3 - Noxious gases
4 - Octalene

Capacity of Activated Coconut Shell Charcoal
for specific vapors

4 - Octane
4 - Odors
4 Odorants
4 - Onions
4 - Organic Chemicals
4 - Ozone
4 - Packing house odors
4 - Paint and redecorating odors
4 - Palmitic acid
4 - Paper deteriorations
4 - Paradichlorbenzene
4 - Paste and glue
3 - Pentane
4 - Pentanone
3 - Pentylene
3 - Pentyne
4 - Perchloroethylene
4 - Perfume, cosmetics
4 - Perspirations
4 - Persistent odors
4 - Pet odors
4 - Phenol
3 - Phosgene
4 - Pitch
4 - Plastics
3 - Poison gases
3 - Pollen
4 - Popcorn and candy
4 - Poultry Odors
2 - Propane
3 - Propionaldehyde
4 - Propionic Acid
4 - Propyl Acetate
4 - Propyl Alcohol
4 - Propyl Chloride
4 - Propyl Ether
4 - Propyl Mercaptan
2 - Propylene
2 - Propyne
3 - Putrefying substances
4 - Putrescine
4 Pyridine
2 - Radiation products
4 - Rancid oils
4 - Resins
4 - Reodorants
4 - Ripening fruits
4 - Rubber
4 - Sauerkraut
4 - Sewer odors
4 - Skatole
3 - Slaughtering odors
4 - Smog
4 - Smoke
4 - Soaps
3 - Solvents
4 - Sour milks
4 - Spilled beverages
4 - Spoiled food stuffs
4 - Stale odors
4 - Stoddard solvent
4 - Stuffiness
4 - Styrene Monomer
4 - Sulfur compounds
2 - Sulfur Dioxide
3 - Sulfur Trioxide
4 - Sulfuric Acid
4 - Tar
3 - Tarnishing gases
4 - Tetrachloroethane
4 - Tetrachloroethylene
4 - Theatrical makeup odors
4 - Tobacco smoke
4 - Toilet odors
4 - Toluene
4 - Toluidine
4 - Trichlorethylene
4 - Turpentine
4 - Urea
4 - Uric Acid
4 - Valeric Acid
4 - Valericaldehyde
4 - Vapors
4 - Varnish fumes
4 - Vinegar
3 - Vinyl Chloride
3 - Viruses
3 - Volatile materials
4 - Waste products
3 - Wood alcohol
4 - Xylene

Some of the contaminants listed in the table are specific chemical compounds, some represent classes of compounds, and others are mixtures and of variable composition. ACSC's capacity for odors varies somewhat with the concentration in air, with humidity and temperature, and with the actual velocity used through the filters. The numbers given represent typical or average conditions and might vary in specific instances. The values in the table have been assembled from many sources including laboratory tests and field experience. In cases where numerical values were not available, the author has listed his opinion of the probable capacity based on general experience. The table should be used as a general guide only.

APPENDIX J.

PAYLOAD SHROUD

P R E F A C E

This document is the final technical report on the Skylab Payload Shroud Design Development and Flight Program. The effort was conducted under the authority of Contract NAS9-6555, Schedule I, and MDAC Intercomponent Work Order Y9S075.

This document is submitted to the NASA in conjunction with MDC Report E0899, "Airlock Module Final Technical Report," to complete the contractual requirement for submittal of an Airlock Project Final Technical Report.

PRECEDING PAGE BLANK NOT FILMED

CONTENTS

NOTE - The Final Technical Report for the remainder of the Airlock Modules is presented in MDC Report E0899.

LIST OF FIGURES

LIST OF TABLES

Section 1
INTRODUCTION

In August 1969, MDAC was requested by the NASA/MSFC AAP Program Office to perform a preliminary design analysis study of the AAP-1 Payload Shroud (PS) and the Apollo Telescope Mount (ATM) Deployment Assembly (DA). This study was completed 8 September 1969 and, based on the trade studies, a radially segmented PS configuration was selected for the AAP-1 Mission.

The PS design configuration was further definitized during the CCP No. 49 proposal activities to incorporate the PS and DA design and development activity into the MDAC Airlock Project. CCP No. 49 was submitted to NASA/MSFC on 31 October 1969, and concurrently detail design of the PS and DA was initiated by MDAC.

During the course of this program, the AAP activity became designated as the Skylab A Program. The Skylab PS design and development program was completed, and PS Flight Unit No. 1 was successfully flown as part of Skylab 1 on 14 May 1973.

The Skylab PS design and development was conducted as part of the MDAC Airlock Module Project, Contract NAS9-6555, Schedule I. The PS program required development and manufacture of two identical flight articles (U1 and U2), a complete full scale test article (PS S/N 000001) essentially identical to the flight unit, a structural test article for MSFC testing (DA-118-10) which included the aft cone segment plus forward cylinder segment, and the associated GSE for both flight and test articles. Design integration and detail design activities were conducted at the Contractor's facilities at Saint Louis, Missouri, and Huntington Beach, California. The PS was fabricated at MDAC-Huntington Beach. All Huntington Beach effort was conducted as part of the Airlock Project in accordance with MDAC Intercomponent Work Order (ICWO) Y9S075.

This Final Technical Report, MDC Report G4679, presents a concise history and summary of the development and flight program of the Skylab Payload Shroud. Results of the Payload Shroud efforts have been documented in Airlock Module Formal Reports, Design Review Packages, and also by ICWO Technical Transmittal Memoranda (TTM). Development and qualification test results, design analyses, problem reports, and problem resolution actions were documented as TTM and ICWO Y9S075 Data Item transmittals. This final report includes abstracts of the significant technical documentation.

MDC Report E0899, "Airlock Module Final Technical Report," presents a concise history and summary of the development and flight program of all other elements of the Airlock Module, i.e., the Structural Transition Section (STS), the tunnel and trusses, the Fixed Airlock Shroud (FAS), and the ATM Deployment Assembly (DA).

These two reports, MDC Reports G4679 and E0899, together comprise the Skylab Airlock Project Final Technical Report.

Section 2
DESIGN APPROACH

Design approach guidelines were established at the onset of the program and were strictly adhered to throughout the design and development activity. A simple, state-of-the-art, structural and mechanical design approach was selected. Requirements for achieving high confidence in system performance while maintaining moderate costs of the hardware were major considerations during the program. For example, the design utilized ultimate safety factors sufficiently high to eliminate the need for full-scale structural testing. Parts and subsystems, however, were tested to the extent necessary to completely assure design adequacy.

An all-aluminum, ring-stiffened, semi-monocoque shell was selected for the PS basic structure. The skin-thickness/ring-spacing parameters were optimized to provide adequate strength, and provide the required acoustic attenuation without need for special attenuation coatings. At the same time, the PS was designed to meet the CEI maximum weight limitations.

A quad section radial separation approach was selected. The MDAC non-contaminating longitudinal thrusting joint device was selected for the separation system. Discrete latches were needed for structural ties across the two major ring frames: the PS base ring and the cone-cylinder intersection ring. Linear explosive devices were selected to provide the power to actuate both the thrusting joint system and the discrete latch system. A Saturn qualified EBW system was selected for the electrical/ordnance system.

An MDAC developed slide-off disconnect base attach system was used; the PS quad-section motions during the jettison event automatically disengage the PS from the Airlock FAS. Lanyard electrical umbilicals, PS to FAS, automatically disconnect during the jettison event.

The PS was designed to structurally support the ATM during ground operations and during flight prior to the PS jettison event. The ATM structural support connection was designed such that the ATM outrigger support points are automatically released by PS quad-section motions during the jettison event.

The initial basic design was completed during the spring of 1970. The test unit PS, fabricated to this design, was completed in October 1970 and shipped to the NASA Plum Brook Station for jettison demonstration tests. Several minor structural reinforcements were added to resolve problems encountered during the first separation test (Plum Brook 1, or PB-1). A thrusting joint tube rupture problem was encountered during PB-2 (February 1971) and, as a result of this problem, and the ensuing engineering investigations, the separation system transfer and manifold systems were strengthened. The test unit was retrofitted with the redesigned tubing systems prior to PB-3. The PS PB-3 system demonstration was conducted in June 1971 and was completely successful. The flight units were made identical to the final PB-3 test unit configuration.

2.1 PRELIMINARY DESIGN STUDIES

The PS preliminary design studies are documented in MDAC Publications "Preliminary Design Study, AAP Saturn Workshop Payload Enclosure and ATM Deployment Assembly" dated 8 September 1969, and "CCP No. 49, Cost and Delivery Proposal, Integrated Payload Shroud and ATM Deployment Assembly" dated 31 October 1969.

The preliminary design studies were, in fact, technical trade studies of the PS and DA configurations as functions of the Skylab Cluster System design requirements ("configuration" included test, manufacture, and prelaunch operations as well as design aspects).

The trade studies on the PS evolved into two major considerations: First, two alternatives were available for time of jettison — during launch ascent or in orbit. Second, four separation concepts were considered:

- Segmented - Segmented into four 90-degree elements and jettisoned laterally.
- Over Nose - Jettisoned axially over the nose.

- Over Nose - Peeled - One piece jettisoned axially over the nose after sections were cut and hinged outward to enhance initial separation clearance.
- Nose Cone Over Nose - Aft section segmented.

Study parameters included jettison control, separation devices and systems, ATM/DA requirement influences on PS design, reliability, verification testing, recontact of jettisoned segments with the cluster, costs, operational impacts, manufacturing aspects, impact on other modules, and schedule compatibility.

The selected PS configuration was the radially segmented design to be jettisoned in orbit. See Figure 2.1-1. The design has growth capability for an in-ascent jettison. PS jettisoning is accomplished by first releasing the discrete latches; the thrusting joint system is then actuated to stage the PS segments.

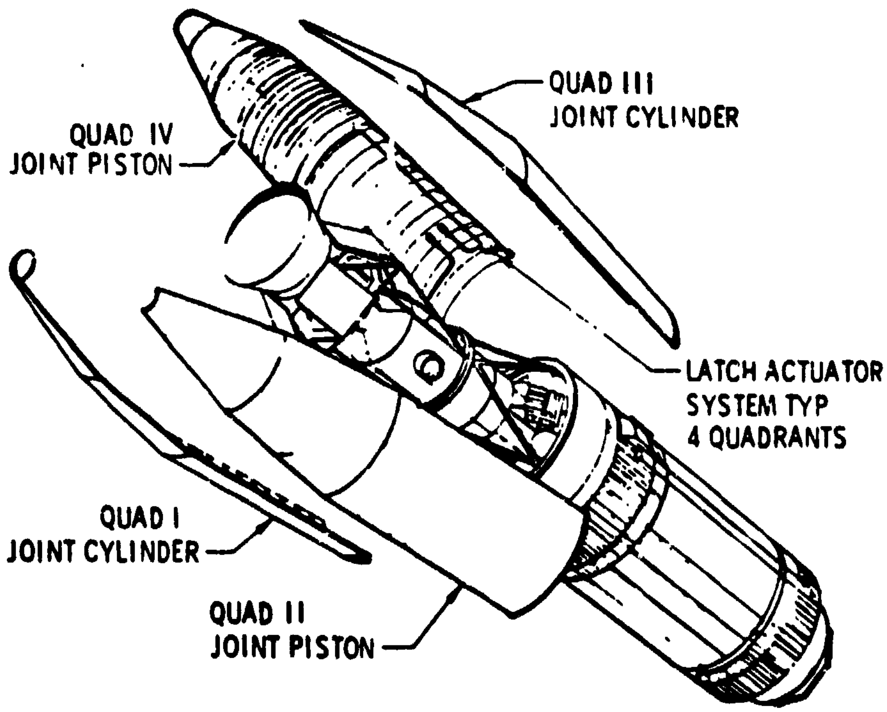


Figure 2.1-1. Radially Segmented Payload Shroud Configuration

2.2 DESIGN AND PRODUCT CONFIGURATION REQUIREMENTS

The basic performance, design, and ground test requirements for the Skylab PS are established by CEI Specification MDC E0047, Part I, Revision G, dated 19 January 1973. The original issue was released 31 October 1969, concurrent with the start of the detail design activity (CCP No. 49). ECP design requirement changes incorporated from the original issue are tabulated in Table 2.2-1.

The performance, design, and ground test requirements include the subtier documents to MDC E0047, Part I, as listed in Table 2.2-2. A summary listing of all pertinent ECP's, including CEI effectivity, change schedule and status are contained in the Airlock Configuration Status Accounting Report MDC E0469.

The PS was designed to provide an environmental shield and aerodynamic fairing for the Saturn Workshop (SWS) forward of the Fixed Airlock Shroud (FAS) portion of the Airlock Module (AM), and was designed to support the Apollo Telescope Mount (ATM) during prelaunch, launch and boost phases. The PS provided a noncontaminating separation system which would jettison the PS from the Skylab Cluster during orbit.

General design features of the PS include the following major system elements: (1) Biconical nose and 22-ft diameter cylinder aluminum shell structure, (2) separation system including the discrete latch system and the longitudinal thrusting joint system, (3) electrical/ordnance system, (4) instrumentation system, and (5) nose cone purge duct system.

Detail provisions for the ground test program are specified in subtier document MDC E0041 and are discussed in detail in Paragraph 3.2.

The basic product configuration and acceptance test requirements are established by MDC E0047, Part II, Revision C, dated 19 January 1973. The original issue was released 15 January 1971. The product configuration baseline was established at acceptance review of S/N 000002. The ECP product configuration changes incorporated from the original issue are tabulated in Table 2.2-3.

The product configuration and acceptance test requirements include the subtier documents to MDC E0047, Part II, as listed in Table 2.2-4.

Table 2.2-1

PAYLOAD SHROUD DESIGN REQUIREMENT ECP'S

ECP Number	Description
088-1	Stress Corrosion Survey
092-1	Survey of Materials for Compliance with MSFC-SPEC-101A
116-1	General Update to Reflect Technical Baseline
127-1R1	Rainproofing
168-1	ICD 65ICD9001 Skylab I Proturbrance and Access Location
182-1R1	Wide Band Data Instrumentation System
194-1	ICD 65ICD9023 LC-39 VAB High Bay Skylab I
365	Cleaning, Sealing, Storage and Barge Shipment
71[illegible]-1	Access Platform Provision Revisions

Table 2.2-2

PAYLOAD SHROUD CEI SPECIFICATION PART I MDAC SUBTIER DOCUMENTS

Report Number	Description
E853	Airlock Electromagnetic Interface Control Plan
F319	Airlock Equipment Environmental Design Requirements
F483-1	Saturn V Airlock Module Structural Design Criteria and Loads
G462	Airlock Materials Evaluation Program
G671	Airlock Safety Plan
H031	Electromagnetic Compatibility Control Plan for AM
MDC E0041	PS Development and Qualification Test Plan
MDC E0466	PS Contamination Control Plan

Table 2.2-3

PAYLOAD SHROUD PRODUCT CONFIGURATION ECP's

ECP Number	Description
182-1R1	Wide Band Data Instrumentation System
365	Cleaning, Sealing, Storage and Barge Shipment
550	End-to-End Electrical System Test
653	Incorporate PS Configuration List
714	Access Platform Provision Revisions
773	Update PS Configuration List

Table 2.2-4

PAYLOAD SHROUD CEI SPECIFICATION PART II MDAC SUBTIER DOCUMENTS

Report Number	Description
MDC E0041	PS Development and Qualification Test Plan
MDC E0042	PS Acceptance Test Plan
E854	Quality Assurance Provision (Plan)

2.3 DEVELOPMENT AND QUALIFICATION TEST PLAN

The ground test plan established for the Skylab PS program is described in Report MDC E0041, dated 14 January 1970 including Contract Document Change Notices (CDCN's) 001 and 002 to that document. CDCN 001 is an editorial update of the document and CDCN 002 provides for additional PS pin-puller qualification tests. This plan established the requirements for the ground test program used to provide design data to evaluate and verify new and modified components and structural assemblies of the PS. The test plan requirements are outlined in Table 2.3-1. Development and qualification test were conducted by MDAC-Huntington Beach, and the space simulation firings were conducted at the NASA Plum Brook Station, Sandusky, Ohio.

2.4 ACCEPTANCE TEST PLAN

The PS acceptance test plan established for the program is described by Report MDC E0042, dated 14 January 1970 including CDCN 001 and 002 to that document. CDCN 001 is an editorial update of the document and CDCN 002 provides for an end-to-end checkout of the electrical/ordnance system. This plan establishes the requirements for the acceptance test program used to provide a measure of overall quality of the completed product and a demonstration that each production shroud is functionally flight ready at delivery. The acceptance test plan basic requirements are outlined in Table 2.4-1. Detail results of the acceptance test program are described in Paragraph 4.1.

Table 2.3-1

PAYLOAD SHROUD BASIC DEVELOPMENT TEST REQUIREMENTS

Design Development Tests - Tests conducted to verify panel structural load capability, to optimize the separation joint rivet patterns, verify the detonator adapter block design and obtain acoustic data.

- o Component Element Structural Tests
- o Panel Separation Development Tests
- o Confinement and Propagation Tests
- o Component Element Acoustic Test

Qualification Tests - Tests conducted to demonstrate that flight configuration hardware/assemblies satisfy design requirements under report F319 environments.

- o Discrete Latch Qualification Tests
- o Diode Module Shock/Vibration Qualification Tests
- o Acoustic Noise Measuring System Qualification Tests
- o Vibration Measuring System Qualification Tests

System Level Verification Tests - Tests conducted to demonstrate proper function of all PS systems under simulated space environment conditions.

- o Space Simulation Firing

Table 2.4-1

PAYLOAD SHROUD BASIC ACCEPTANCE TEST REQUIREMENTS

Pre-Installation Acceptance Tests - Tests conducted on components prior to installation in the cone and cylinder sections:

- o Ordnance Components
  - Linear Explosive Assemblies
  - EBW Detonators
- o Separation Joint Bellows
- o EBW Firing Units

Assembly Acceptance Tests - Tests conducted on completed cone and cylinder sections:

- o Discrete latch fit check
- o Electrical installation checkout
- o Cylinder structural interface compatibility
- o Base tension fitting interface compatibility
- o Cone weight and balance
- o Cylinder weight and balance
- o PS weight and balance

Prepare for Shipment

- o Clean significant surfaces
- o Bag and install protective cover kit

2.5 INTERFACE REQUIREMENTS

The Payload Shroud interface requirements are imposed by reference to the Airlock Module Interface Control Document Contractual Index and Status Report in the CEI Specification. In addition, interface requirements with other MDAC modules and GSE are imposed by reference to requirements drawings and ICWO technical transmittal memoranda.

- The PS/ATM Mechanical Interface is controlled by NASA/MSFC ICD 13M20726.
- The PS/MSFC Work Platform Mechanical Interface is controlled by NASA/MSFC ICD 12M20988.
- The PS Protuberance and Access Locations are controlled by NASA/MSFC ICD 65ICD9001.
- The PS/EBW Firing Unit Electrical and Mechanical Interface is controlled by NASA/MSFC ICD 40M37573.
- The PS/EBW Pulse Sensor Electrical Interface is controlled by NASA/MSFC ICD 40M06218.
- The PS interface requirements with the KSC facilities are controlled by the following NASA/MSFC ICD's:
  65ICD9023-LC-39, VAB High Bay SKYLAB I (Mech)
  65ICD9212A-SWS GSE LC-39 Facility Cable (Elec)
  65ICD9542 SKYLAB I Pad and VAB System Requirements (Mech)
  66ICD8042 SKYLAB (AM/MDA/ATM) O&C Mech System Requirements (Mech)
- The PS/FAS Mechanical Interface is controlled by MDAC Drawing 61L330005.
- The PS/MDAC Work Platform Interface is controlled by MDAC Drawing 61L330005.

2.6 DETAIL DESIGN

2.6.1 Structural Subsystem Design Approach

The general configuration of the structures subsystem consists of an all aluminum cylindrical section and a biconical nose section. Both the cylindrical section and the nose section are thick skinned, ring reinforced, monocoque structures. The shroud is constructed in four equal 90° segments; the edges are stiffened by the separation rails. The separation rail shear rivets provide structural continuity across the rails to complete the structural shell. The segments

are unlatched and jettisoned pyrotechnically by continuous linear explosive charges located in the longitudinal rails and by latch actuators mounted on the base ring and the cylinder ring at the cone-cylinder intersection. Attachments are provided for the damper arm mechanism and for the service arm of the Launch Umbilical Tower (LUT). Support of launch loads of the ATM is also provided by the structural subsystem. An air conditioning purge duct is routed through the cylinder across the cone/cylinder interface and through the nose cone to a diffuser below the nose cap to purge the upper portion of the PS in the area of the ATM.

The PS general structural arrangement is shown by Figure 2.6.1-1. The forward 25° cone is 182-in. long and the aft 12-1/2° truncated cone is 142-in. long. They are both constructed of 0.25-in.-thick ring reinforced 2024 aluminum skins. The reinforcing rings in the nose are formed 7075 aluminum frames which are structurally attached to the separation rails to complete the structural biconic shell. The nose cap is 0.30-in.-thick, 22-in. radius 6061 aluminun monocoque shell. It is one piece, permanently attached to PS Quad I, and jettisons with Quad I. The base ring of the biconical nose is a 7075 extruded angle that is permanently attached to the aft cone section. It contains a bolt circle in the aft flange for the field joint connection to the PS cylinder.

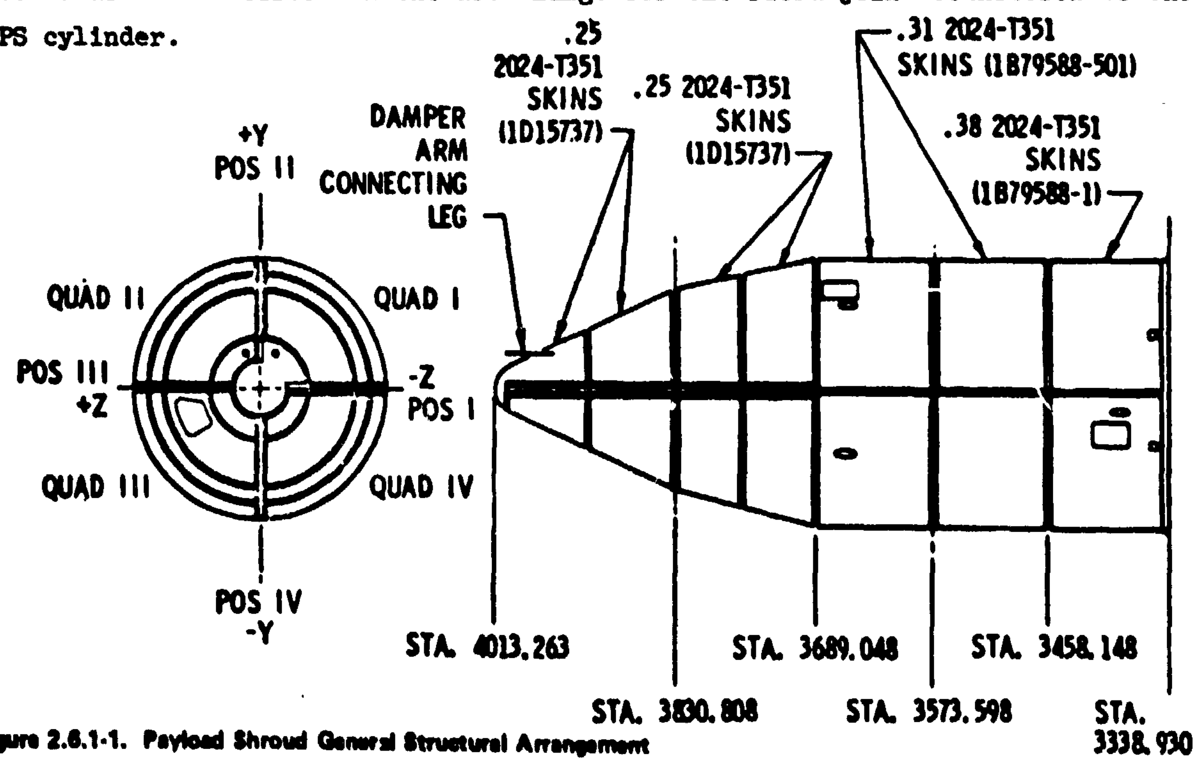


Figure 2.6.1-1. Payload Shroud General Structural Arrangement

The skin panels were constructed in panel jigs and the cone separation rails, including the contained separation system, were completed in subassembly jigs. The complete nose was assembled by loading the four nose rails and all nose cone panels into the biconical nose assembly jig and completing the nose assembly.

The cylinder structure was constructed in a similar manner. It is 350-in. long by 260-in. diam with 0.31-in.-thick 2024 aluminum skins used on the two forward panels and 0.38-in.-thick 2024 aluminum skins used on the aft panel. Cylinder ring reinforcement frames are 7075 I-beam extrusions formed to the circular contour. The major ring frames -- cylinder-cone at forward end and FAS attach at aft end -- were machined from 7075 plate. The complete cylinder was assembled by loading the four cylinder rails, all cylinder panels, the major ring frames and ATM support hardware into the cylinder assembly jig and completing the assembly.

Longitudinal ATM support fittings, with side sway support braces, were built into the upper end of the cylinder to structurally support the ATM support link and, in turn, the ATM outrigger points. The ATM support link provided the interface connection to the ATM and also the required installation adjustment capability.

Figure 2.6.1-2 shows the PS structure breakdown as described above.

The internal surfaces were designed with smooth surfaces, within practical fabrication limitations, to provide capability of meeting the PS cleanliness requirements. A silastic anti-contamination caulking was applied at selected locations on the PS to seal-off debris entrapment areas.

Aluminum structural parts were finished with MIL-C-5541, Class 3 corrosion protection coating (Alodine 1500). This finish, in addition to providing the required corrosion protection, also provides an internal surface with low surface emmissivity that enhances temperature control. The finish provides good electrical bonding between structural joints.

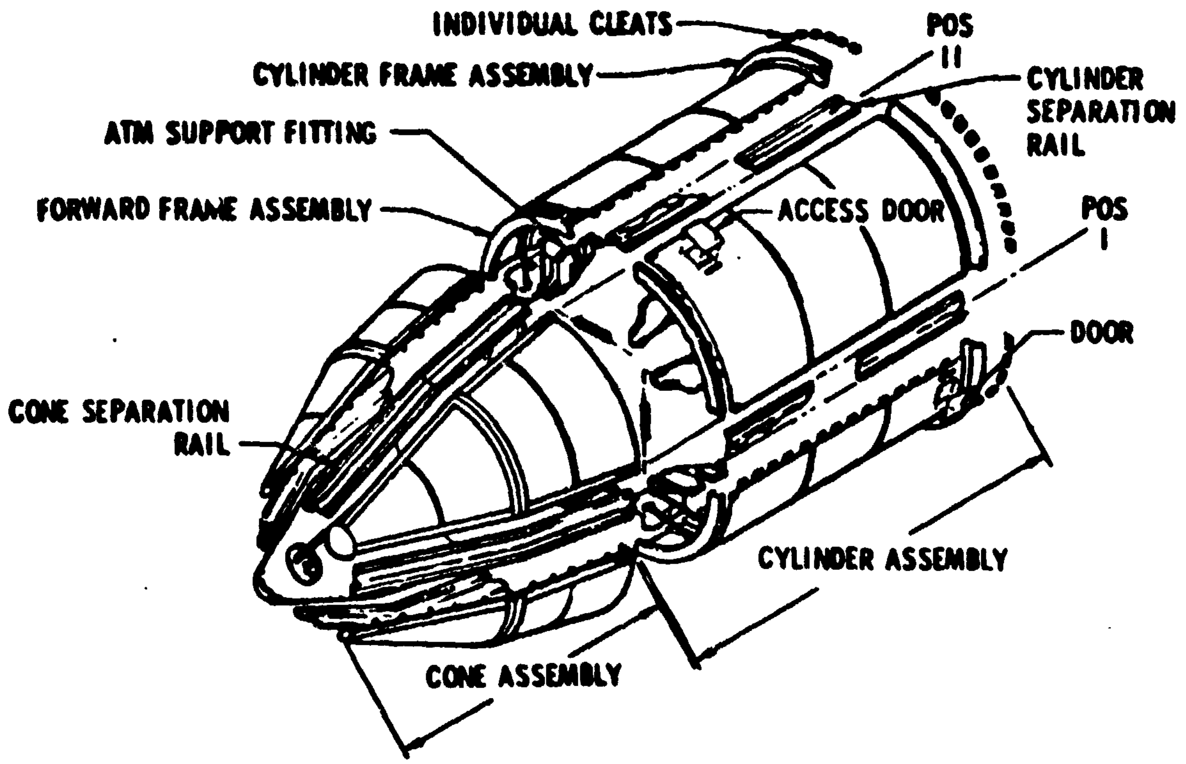


Figure 2.6.1-2. Payload Shroud Structure Breakdown

An all-white external finish was selected to meet ICD finish requirements for thermal control. A small area in the region of the damper arms was coated with DC93-044 external thermal insulation to protect the PS structures from local high-heat fluxes produced by the damper arm protuberances.

2.6.2 Separation Subsystem

The separation system provides a contamination-free jettison of the PS quad sections at the required trajectory. The MDAC non-contaminating thrusting joint concept, sized to provide the necessary separation force and energy, was used. An ordnance-actuated pin-puller system was designed to supplement the separation joint rivet seam strength at discrete high load points. The separation system description is divided into the three main subsystems; 1) thrusting joint system; 2) latch actuator system; and 3) the ordnance devices which actuate these systems.

2.6.2.1 Thrusting Joint System

The MDAC non-contaminating thrusting joint system, located in the longitudinal separation planes between the shroud quadrants, consists of a linear cylinder and piston riveted together to form a rail assembly. See Figure 2.6.2-1. The cylinder is attached to one quadrant and the piston to the other quadrant. Located inside the cylinder rail is a tubular bellows, inside of which is an attenuator tube assembly. The thrusting joint separation system is actuated by initiation of a linear explosive harness inside the vented attenuator tube assembly. The gas generated by the combustion of the linear explosive pressurizes the bellows and forces the piston and cylinder rails apart, see Figure 2.6.2-2. The force shears the rivets and imparts a velocity to the shroud quadrants. All of the products of combustion and residue of the linear explosive is contained within the sealed bellows and tube system. The thrusting joint components are located on Quadrants II and IV of the four quadrant Payload Shroud as shown by Figure 2.6.2-3. Cylinder/piston rail assemblies, one in the cylindrical section and one in the cone section, run the length of each longitudinal thrusting joint. A closed transfer tube system connects the rail assemblies at the cone/cylinder junction, across the nose cap, and at the

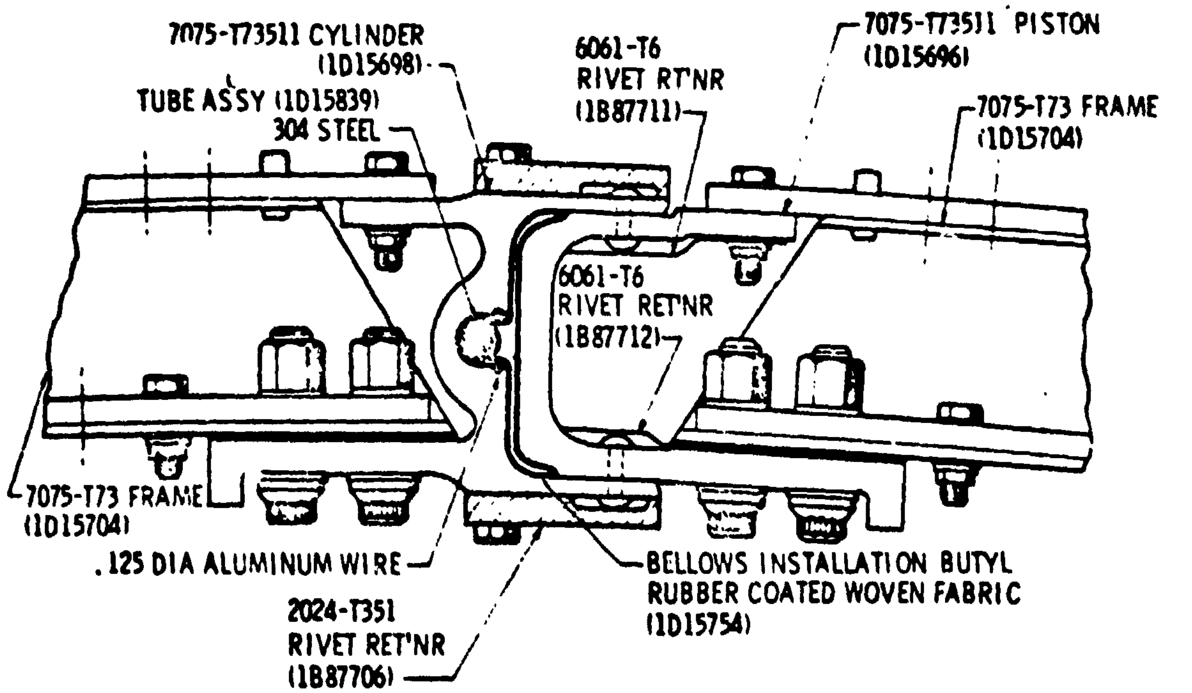


Figure 2.6.2-1. Payload Shroud Thrusting Joint

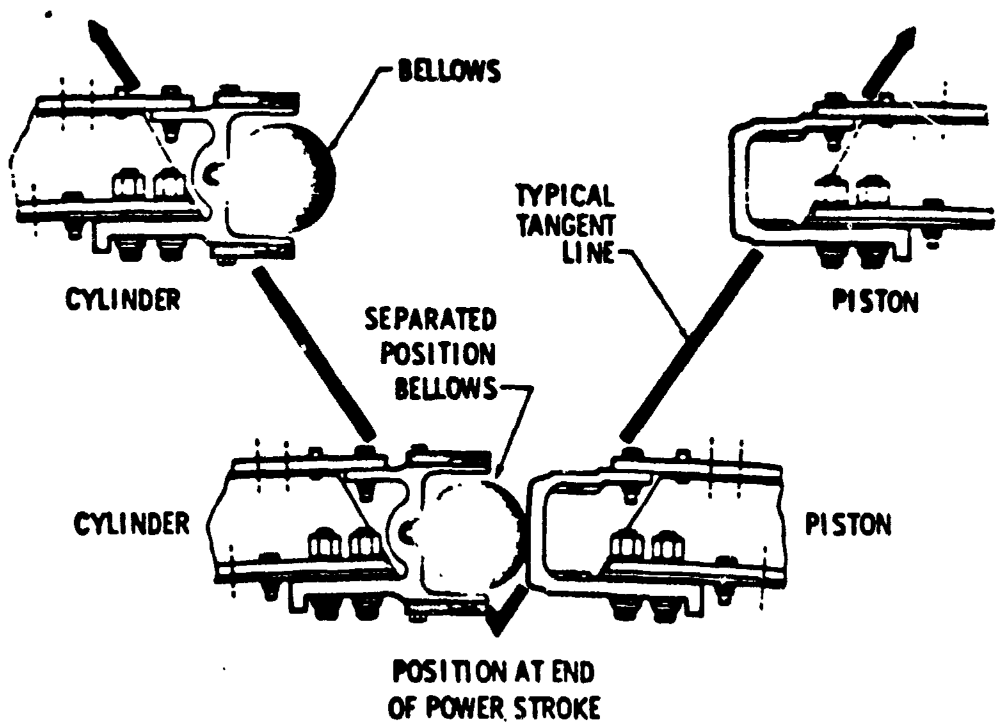


Figure 2.6.2-2. Thrusting Joint Separation Function

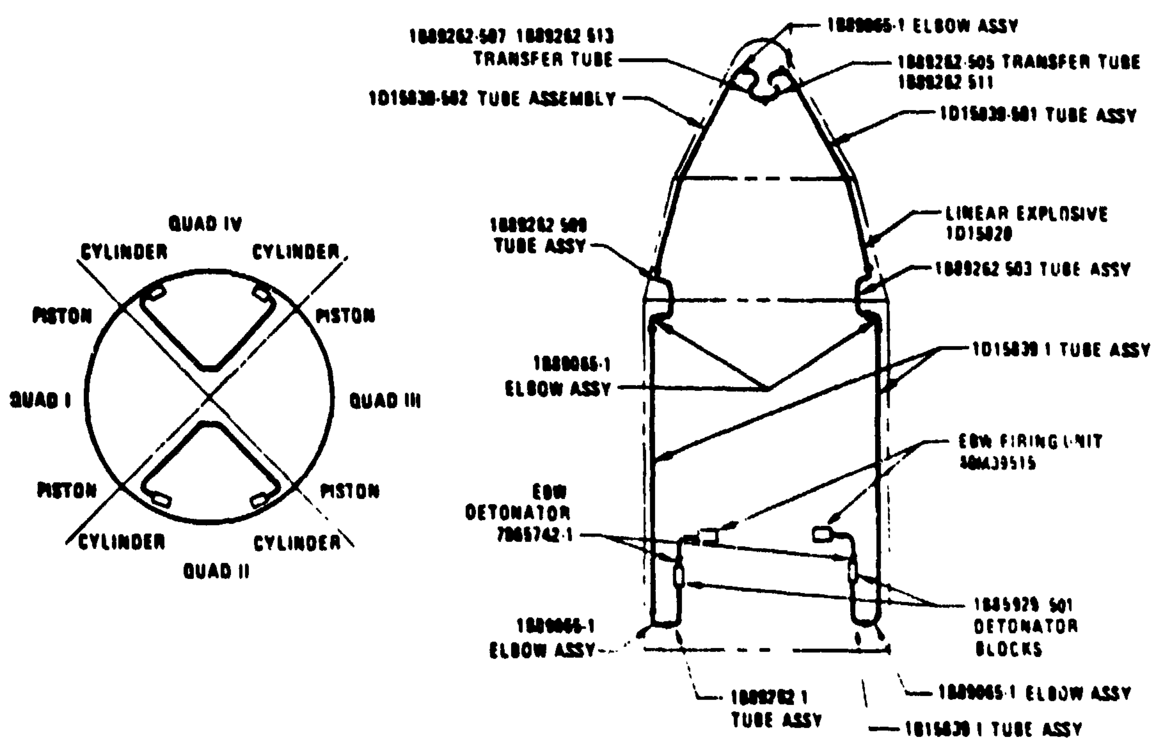


Figure 2.6.2-3. Thrusting Joint System Configuration

base of the shroud to the detonator blocks. The thrusting joint bellows is made of a tubular woven Nomex fabric with a butyl rubber covering on the inside wall.

The ends of the bellows at the end of each rail assembly is sealed with a silicon rubber end seal plug. The ends of the bellows and the end seal plug are confined between the cylinder rail and the cover block, as shown in Figure 2.6.2-4. A nut plate and end plate are pulled together by three screws and compress the rubber end seal plug between them along its longitudinal axis, causing the end seal plug to bulge and form an effective seal with the bellows and attenuator tube. The attentuator tube assemblies consist of inner and an outer stainless steel attenuator tubes assembled as shown in Figure 2.6.2-5 with the inner tube holes indexed 180° from the holes on the outer tube. The attenuator tube assembly is installed inside of the bellows with the holes of the outer tube pointed away from the cylinder rail. This is to allow the combustion gases from the linear explosive to pressurize the bellows while attenuating the explosive blast.

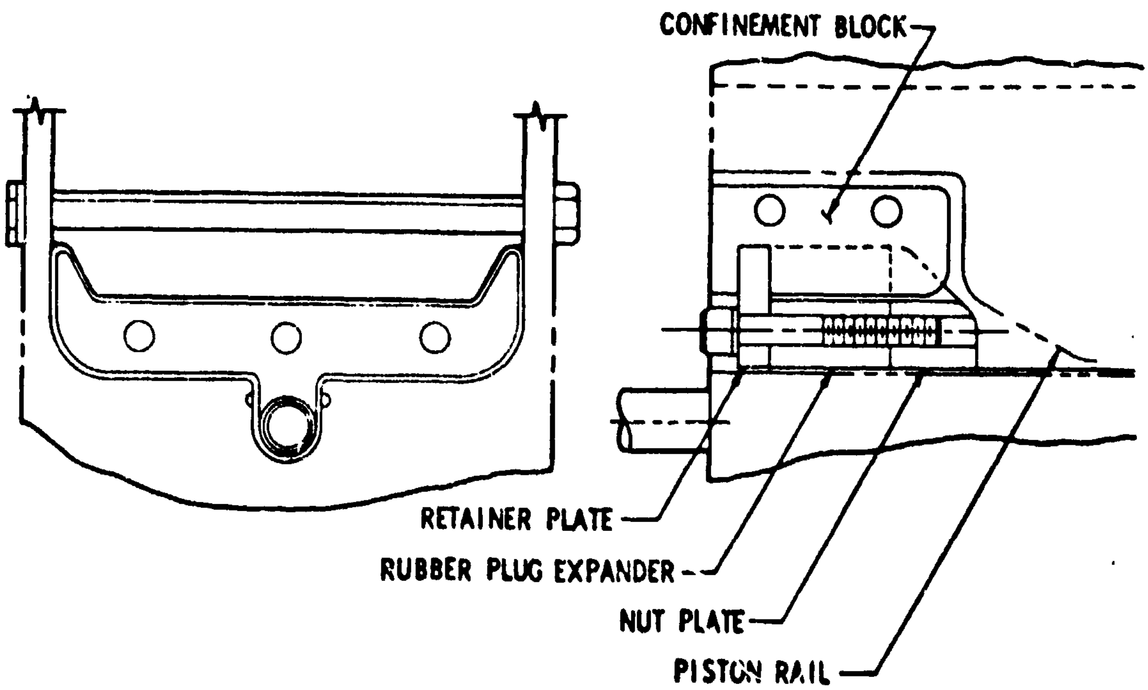


Figure 2.6.2-4. Bellows End Seal Design

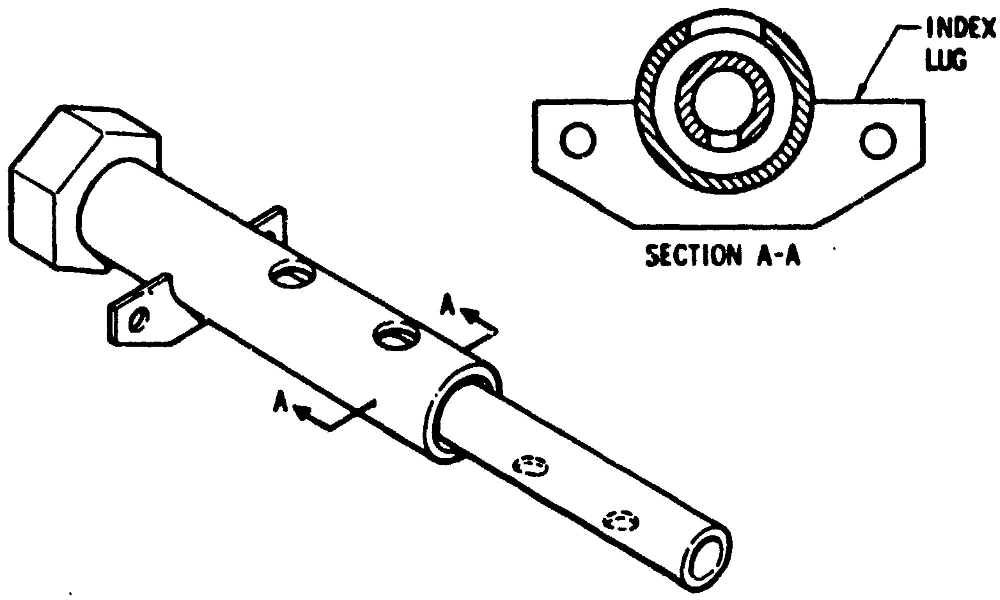


Figure 2.6.2-5. Separation System Attenuator Tube

The attenuator tubes, bellows with end seals and transfer tube system terminate at each end into detonator blocks providing a completely sealed system. The explosive charge is an assembly of seven strands of detonating fuse. The seven strands terminate at each end in a relay cap. This assembly is identified as a Linear Explosive Assembly (LEA). The LEA is installed through the transfer and attenuator tubes of the system and terminates at each detonator block. The relay caps of the LEA are secured and pos ioned in the detonator blocks with a split rubber spool, washer and detonator adapter (see Figure 2.6.2-6). Detonators are installed in each detonator adapter and interface with the LEA relay caps. The gap between the detonator output end and the relay cap is controlled by dimensions and are verified prior to assembly. Redundancy of the system is accomplished by initiation of each end of the explosive train.

2.6.2.2 Latch Actuator (Pin-Puller) System

The pin-puller system provides additional strength across the separation planes to provide a load path for concentrated loads at the Payload Shroud aft ring and at the cylinder/cone junction by a link-and-clevis arrangement. The

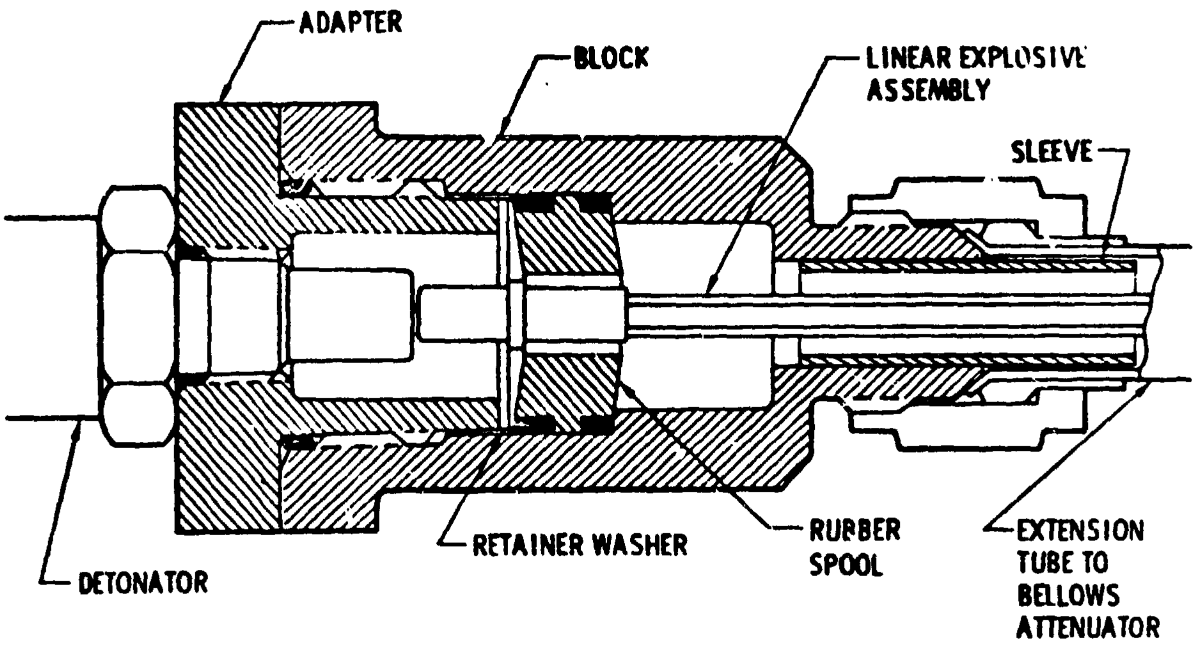


Figure 2.6.2-6. Detonator Block Assembly

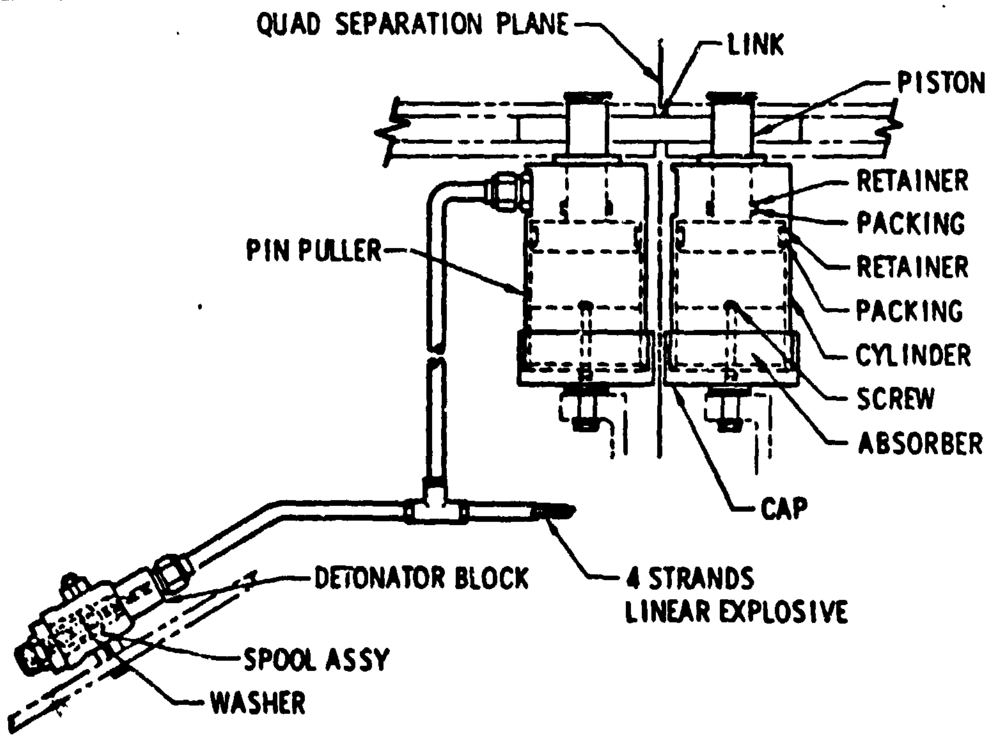


Figure 2.6.2-7. Latch Actuator System Components

link is installed across the separation plane into clevises on each quadrant as shown on Figure 2.6.2-7. The link is pinned onto each clevis by the extended pin of the pin pullers. The link is released from the clevises when the pins are pulled from the link. The pin puller assembly consist of a piston cylinder and an energy absorber. The piston rod is the clevis pin. The energy absorber is an aluminum honey-comb crush block assembled in the cylinder and decelerates the piston at the end of its stroke. There are four pin pullers in each quadrant of the Payload Shroud. They are connected to a common closed tubing manifold system as shown on Figure 2.6.2-8. The ends of the manifold tubing system terminate at detonator blocks. A four strand linear explosive assembly similar to the thrusting joint LEA is installed in the manifold and terminated in the same manner in detonator blocks. Gas pressure generated in the manifold by initiation of the LEA is directed to the under side of the pin puller pistons. This pressure produces twice the maximum required force to pull the pins from the clevis. The pin puller system is redundant in two ways; either of the two pin pullers engaged in a link will release the tie across the separation joint and the LEA will function by initiation from either end.

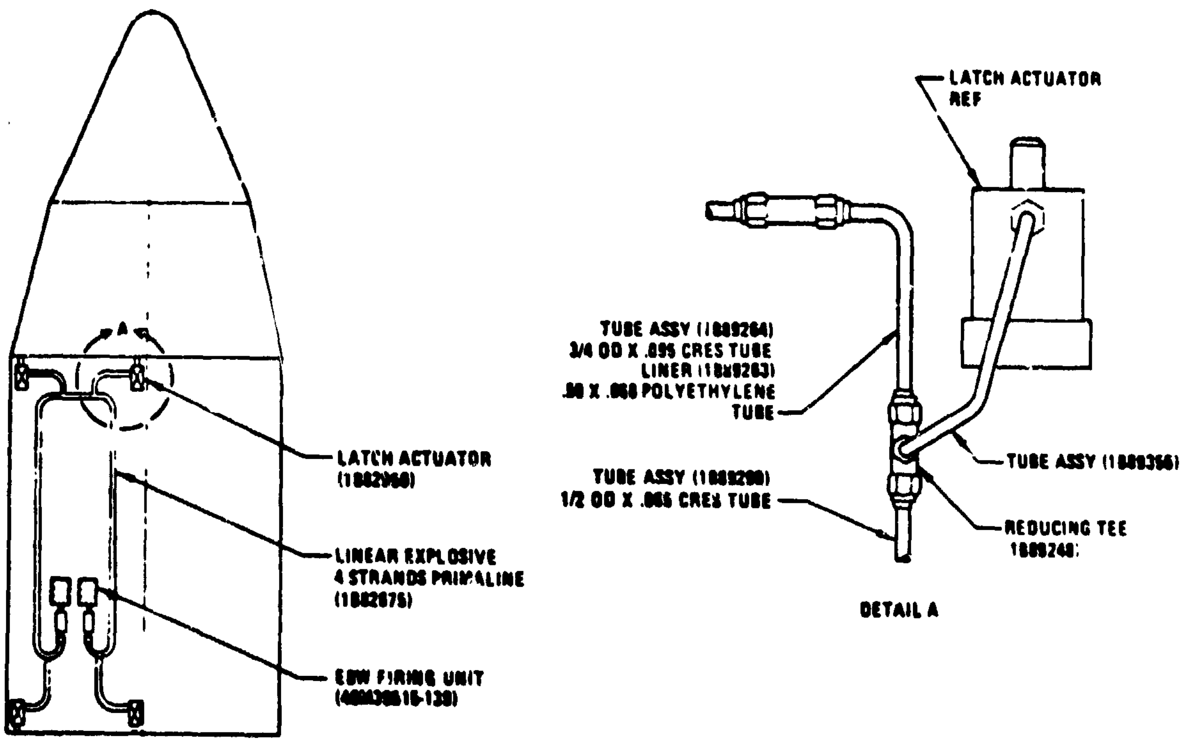


Figure 2.6.2-8. Latch Actuator System (Typical per Quadrant)

2.6.2.3 Ordnance Devices

The linear explosive assemblies, described in detail above, are initiated by exploding bridgewire (EBW) detonators. The detonator fires across the gap maintained in the detonator block into the LEA end cap. A relay charge in the end cap transfers the detonation front from the detonator to the linear explosive fuse. The Linear Explosive Assembly used in the thrusting joint system is made of seven strands of linear explosive, and the assembly used in the pin puller system is made of four strands of linear explosive. Each strand of detonating fuse consists of an explosive core, a woven fabric sock, and a polyethylene jacket. The explosive core of each strand is pentaerythrite tetranitrate (PETN). The relay charge is also PETN and is pressed into the end cap and the ends of the linear explosive are bonded and crimped on. The exploding bridgewire (EBW) type detonator previously qualified and used to initiate the ordnance components on the Saturn IV stage, was requalified to the upgraded Payload Shroud vibration requirements.

2.6.2.4 Electrical

A Saturn qualified EBW system was selected for the basic electrical system equipment. Titan qualified lanyard actuated connectors were selected for the electrical disconnect interface at the FAS.

Each quad-section has an independent electrical system. The electrical system in each quad-section consists of two firing units for the discrete latch system EBW's, and two interface connectors. Quad-section II and IV also includes two firing units (each quad-section) for the longitudinal EBW's. The proper separation of the PS requires that the discrete latch system operate before the longitudinal separation joint operates. The interface connectors provide the payload shroud with electrical system power from the AM and sequencing commands from the launch vehicle Digital Computer or AM DCS. The electrical installation is designed to provide a two-wire system; the shroud structure is not used as a current return path. The electrical system components are RF bonded to the PS structure. Component locations permit easy access so that checkout operations are facilitated and malfunctioning parts can be readily removed and replaced at the launch site.

A block diagram of the PS electrical system is shown by Figure 2.6.2-9. Electrical system operation of the PS equipment is as follows:

- Firing units receive low voltage input power from the AM; the low voltage is converted to a high voltage and used to charge a self-contained capacitor device. A trigger input to the firing unit causes the capacitor to discharge and a short duration, high voltage pulse is delivered to the EBW.
- Discrete latch firing units are operated initially. After a delay,the longitudinal separation joint firing units are operated. The delay between the operation of the discrete latch and the longitudinal separation joint EBW's is necessary to allow flight controllers time to verify proper latch actuation.
- Power input and trigger signals are supplied to the shroud electrical system by means of interface connectors located in each shroud sector.

During checkout of the PS electrical ordnance system, Pulse Sensors (AGE) are installed in place of the EBW detonators. The pulse sensors check the output of the EBW Firing units and produce a go/no go signal. The wiring for the Payload Shroud Pulse Sensors is routed through the Payload Shroud/Airlock interface.

Flight instrumentation on the EBW system included telemetry of charge and trigger signal on each firing unit and also the charge level time history.

Other flight instrumentation incorporated in the electrical harnesses was verification of PS separation (lanyard connector disconnect discrete) and two dynamic data measurements. An acoustic transducer was mounted on the ATM mount structure in Quad I and a vibration transducer was mounted on the ATM mount in Quad III. The readout of the instrument was through the AM and IU telemetry system.

The Flight PS used EBW Firing Unit P/N 40M39515-139. The -139 unit is essentially the same as preceding Saturn type units except that the output cable material and the paint on the case was changed to prevent outgassing.

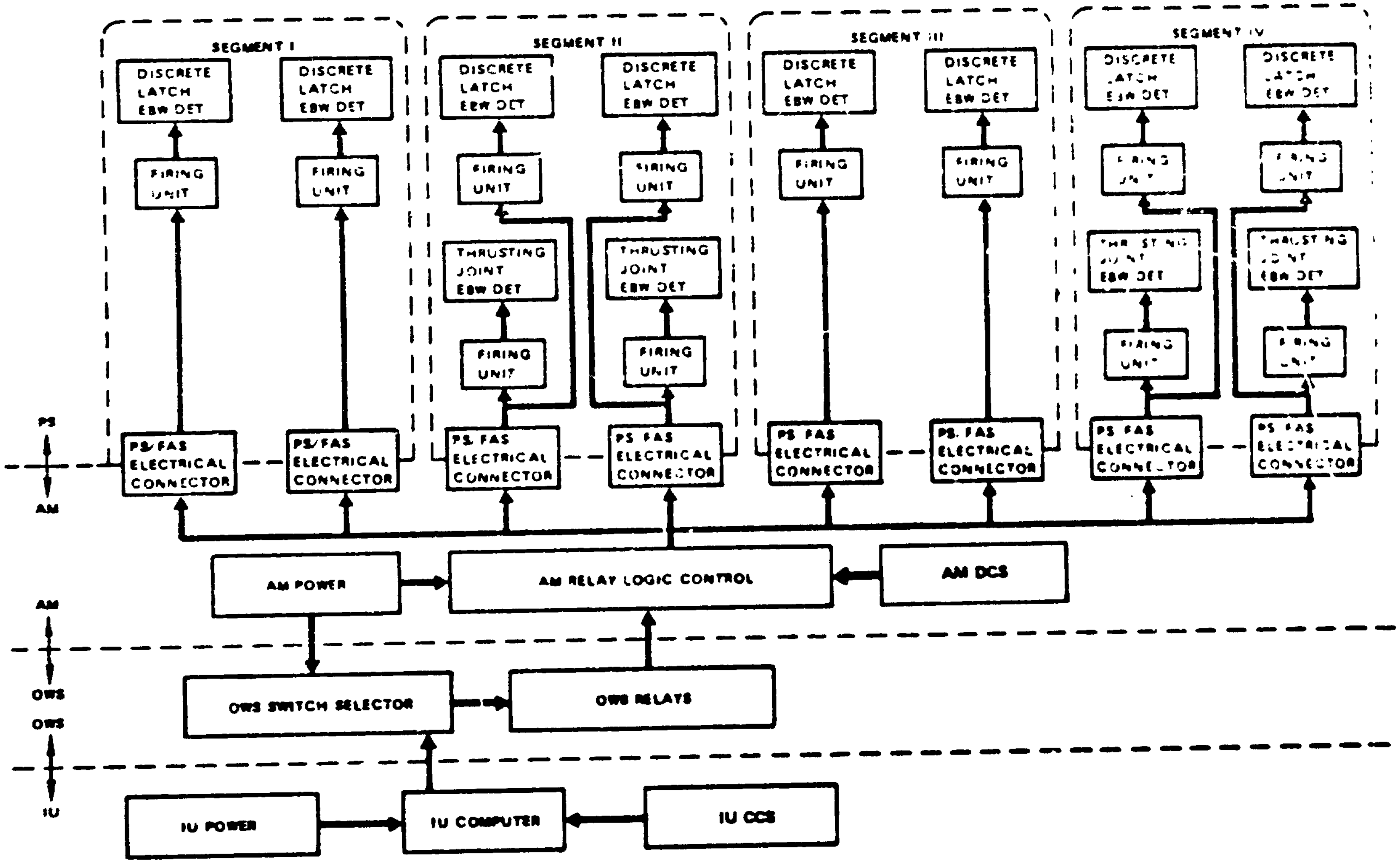


Figure 2.6.2.9. Electrical/Ordnance System Block Diagram

2.7 MASS PROPERTIES

The launched weight of the Airlock Module Payload Shroud was 25,646 pounds including the non-separable payload support and the attach ring. The specification control weight (excluding external insulation) is 26,024 pounds. The margin between the launched weight (less 36 pounds of external insulation) and the control weight was 414 pounds. A weight history of the Payload Shroud is presented in Table 2.7-1. The payload shroud weight was verified by weight measurement tests.

Table 2.7-1

PS WEIGHT GROWTH HISTORY
(pounds)

PDR Dec 1969	CDR Aug 1970	S/N01 (Test Unit) Sept 1970	S/No2 Flight Unit No. 2 Sept 1971	S/N03 Flight Unit No. 1 July 1972
24,000	24,750	25,000	25,753	25,646

2.8 NEW TECHNOLOGY

Two new technology disclosures were transmitted during the PS development program (Data Item 1.4).

The first to be developed in 1970 was the integrated latch pressure release system. Since the thrusting joint used gas pressure from a linear explosive to function the joint, it was determined that a similar linear explosive pressure producer could be used to actuate the integrated latch system. Tests were conducted using linear explosive, Primaline, in hydraulic tubing attached to a standard hydraulic cylinder. These tests were successful and the current integrated pressure latch release system was established.

Another new technology, developed in 1971 relates to a method for preventing the rupture of metal tubing in which multiple strands of linear explosive are detonated. This technology was developed during the separation system tube rupture investigations.

The tube rupture problem was traced, in part, to an interaction between adjacent strands of Primaline resulting in a high velocity jetting action, or Munroe effect, which scored and weakened the tube wall allowing it to be ruptured by the subsequent gas pressure. It was further noted that this action was most severe when the linear explosive was directly in contact with the tube wall.

The problem, then, was to prevent this scoring action and subsequent tube rupture without materially increasing the size or weight of the tubing. This indicated the use of a liner material to keep the explosive strands away from the tube wall. The liner material should be readily available, light weight, flexible (to be easily installed in the curved sections) and of such a size that it would slip within the 3/4-inch tubing and still leave room inside for the multiple strands of linear explosive. A low coefficient of friction was also desirable to ease problems in threading the linear explosive through the tube.

Commercially available polyethylene tubing met all the requirements and proved to be a satisfactory liner material. This liner material acts as a spacer, preventing the jetting action from scoring the tube walls. It also serves a secondary function, partially absorbing and reducing the explosive shock which is transmitted to the tube wall.

Section 3
DESIGN VERIFICATION PROGRAM

The PS design and development activity included a comprehensive analysis and test program to verify each performance/design requirement line item. MDAC Report G308, Volume II presents a complete tabulation of the documentation, method, and organization responsible for verifying the design and product configuration specification requirements. Abstracts of the analyses, testing and design review activity are contained in this section.

3.1 DESIGN ANALYSES

3.1.1 Performance/Design Verification

In accordance with Section 10, Appendix K to the Airlock Statement of Work, a performance/design verification report was prepared to list, as line items, PS subsystems and their performance requirements; and to list, against each line item, the title, number and date of issue of the report in which the capability of the subsystem design to meet the performance requirements was verified. For the PS, the documentation of the Performance/Design Verification is contained in MDC Report G308, Volume II, Parts 1 and 2. This volume was prepared in two parts to encompass the data contained in CEI Specification E0047, Part I and Part II. Each performance/design requirement contained in MDC E0047, Parts I and II is listed in G308 along with a direct reference to the document containing the verification method and/or test data.

Reference: G308 Airlock Performance/Design Verification Report (Payload Shroud)

3.1.2 Structural Design Criteria and Loads

Report F483-1 documents the structural criteria and loads used in the design of the Airlock Module including the PS structural assembly. The final loads and criteria are contained in Revision A dated 1 May 1971. The final PS structure was sized to the loads and criteria documented by TTM's PS-ED-048,

dated 4 February 1970 and PS-ED-057, dated 27 February 1970. The TTM documented loads were used for the preparation of the "stress notes" analysis described in Paragraph 3.3.4, below. The PS was verified to comply with F483-1 design criteria by comparison analysis with the TTM loads.

Reference: F483-1 Saturn V Airlock Module Structural Design Criteria and Loads

3.1.3 Equipment Environments and Acceptability Analysis

Report F319 defines the environmental extremes to which the PS equipment may be exposed. The environmental requirements in F319 cover the prelaunch, launch, ascent and orbit phases of the Skylab mission. Detail design criteria include thermal design data, dynamic environments, acoustic environments, and pyrotechnic shock environments.

The previous qualification history of PS equipment items were reviewed to establish their acceptability for the design environments. For those components whose previous qualification was not adequate, and for all new components to be flown on the PS, environmental qualification test requirements were established and tests were run.

The acceptability of PS equipment for the Skylab program was established by a series of Airlock Equipment Acceptability Reviews. Report G499 contains the completed review forms on the equipment. The items of equipment are those identified in Report E935 which lists the qualification status of twelve (12) PS components. All components were qualified by tests and/or similarity analysis.

Reference: E935 Airlock Qualification Status Report
F319 Airlock Equipment Environmental Design Requirements
G499 Airlock Equipment Acceptability Reviews

3.1.4 Structural and Materials

The structural analysis of the PS is contained in informal "Stress Notes" prepared to document the analysis activity (TTM SSP-101, dated 30 July 1970). A factor of safety of 3.0 for ultimate is used, in general, for primary structure. This includes dynamic loads, aerodynamic pressure and thrust, and air induced loads. The primary structure in the ATM support region has an

ultimate factor of safety of 2.0 for ATM support loads and aerodynamic pressure. The ultimate factor of 2.0 is also used for equipment items such as pin pullers, detonators, manifold assemblies and separation joints for separation loads. The high factors of safety are used to maintain high confidence in the structural integrity of the payload shroud and minimize costs due to structural tests and sophisticated analysis techniques.

The stress notes document contains the stress checks of the nose cap assembly, conical section stability, cylindrical section stability, and ring frame bending. The ring frame analysis includes inertia loads at the four ATM rack support points, as calculated by the H527 flexible frame computer program combined with stresses due to airloads as calculated by the SA 80 shell analysis computer program. The aft frame provides the structural load interface with the FAS and transmits shear and compression loads through direct bearing surfaces machined in the frame. Longitudinal tension loads across the interface are transmitted by cleats which bolt to the PS aft frame and hook over the flange of the FAS forward ring. The discrete latch assemblies are analyzed for flight loads and also the ordnance actuation pressure loadings. The longitudinal thrusting joint separation rails, including the shear rivets are analyzed in detail. The rivet pattern was sized to detail load distributions resulting from shell loadings except that rivets were added to the inboard leg of the separation rail to better balance initial separation functional forces and reactions. (This change resulted from panel separation test findings.) Analysis of the ATM support structure, damper arm installation, nose cone purge duct, and GSE platform provisions are straight-forward and are contained in the stress notes.

A metallic/non-metallic material evaluation survey was conducted in accordance with MDC Report G462 dated 20 December 1970. This effort involved the completion of MDAC-E Keypunch Data Forms for metallic parts, the non-metallic material configuration control forms for non-metallic parts, and the Parts Breakdown List for purchased parts.

A stress corrosion review of metallic materials was conducted for conformance to NASA document 10M33107, "Design Guidelines for Controlling Stress Corrosion Cracking." This review disclosed P/N 1B82962, Discrete Latch Piston, to be

made of 17-4PH steel in the H900 condition, a material/temper combination susceptible to stress corrosion cracking per the above document. An evaluation of ground handling, storage and prelaunch loading on the piston showed the maximum sustained stress level attainable, using conservative loads, was expected to be 15,000 psi. Considering the low stress level, the part was judged satisfactory. For added assurance, a special test was conducted on the latch actuator pistons. The original design material and temper were accepted.

Reference: Informal Design Notes

3.1.5 Acoustics, Vibration and Shock

In order to ensure that the Saturn Payload Shroud would provide the required noise reduction, a preliminary noise reduction analysis was performed early in the design program to estimate the internal acoustic levels. The noise reduction for the shroud was based on having an internal acoustic level which would require minimum requalification of previously flown hardware. Standard architectural acoustical techniques were first utilized in the preliminary analysis and resulted in predicted internal Sound Pressure Levels (SPL's) which slightly exceeded the criteria in the frequency range below 300 Hz for liftoff and in the frequency range from 630 to 1250 Hz for maximum αq/transonic. Because of the degree of conservatism inherent in the approach used in the analysis, a panel test was conducted to improve the estimate of acoustic transmittivity of the PS structure. The preliminary acoustic analysis was revised to take into account the additional data. In addition, previous experiences on other fairings were used to remove other conservatisms. When these conservatisms were removed, the expected internal SPL's were lower than those required. The actual internal acoustic levels for the fairing when exposed to the external launch environments were measured during the full scale stack test run at JSC; they showed the estimated noise reduction of the fairing to be an accurate estimate of the actual noise reduction.

Preliminary estimates were made for the random vibration environment on the shroud based on Franken's method. Franken's method is an empirical technique which estimates the random vibration response of a cylindrical vehicle to acoustics based on the surface weight and diameter of the cylinder. These predictions were later modified using flight measurements made on the forward

skirt of the SIV-B. The SIV-B skirt measurements were extrapolated to the shroud configuration to account for the increased surface weight of the shroud and the greater distance of the shroud from the noise source. The preliminary and modified random vibration levels are documented in informal analyses notes. The modified random vibration levels (those using Saturn data) are used as the vibration criteria in MDAC Report F319. Acceleration measurements were made on the shroud during the full scale acoustic test at JSC. The random vibration levels measured on the shroud were lower than the predicted levels except for the skin measurements in the frequency range from 150 to 200 Hz. These levels exceeded the design criteria which was based on predicted levels, and Report F319 was modified to take into account these higher levels. Affected equipment components were re-evaluated in light of the higher levels and appropriate action taken.

The pyrotechnic devices used to separate the shroud result in the surrounding structure being exposed to a high level pyrotechnic shock. Preliminary estimates were made for the shock resulting from this separation based on previous experience with tthese type of devices to help establish the criteria of F319. This criteria was verified by the shock measurements made during the full scale separation test at Plum Brook. A comparison between the criteria and test measurements shows the actual levels to be less severe than the criteria.

3.1.6 Aerothermodynamics

Thermal analyses performed on the Skylab I Payload Shroud are documented in MDC Report No. G0438. The effects of aerodynamic heating during ascent were analyzed and temperature predictions for flight were determined for the payload shroud skin, separation joint, and damper arm attach legs. Due to increased heat transfer resulting from shock interactions emanating from the damper arm attach legs, thermal insulation (Dow Corning DC 93-044) was specified as thermal protection for the shroud in the vicinity of the damper arm attach legs. Data on the DC 93-044 material can be found in MDC Report No. G0923.

Results of the thermal analyses showed that the maximum payload shell temperature remains below 220°F; the maximum temperature of the separation joint

bellows and ordnance remain below 150°F. All of these temperatures are below the allowable limits.

Reference: G0438 Thermal Analysis of the Skylab I Payload Shroud

G0923 Dow Corning Thermal Protection System Materials Evaluation

3.1.7 Reliability and Safety

3.1.7.1 Reliability

The probability for mission success established for the Payload Shroud is 0.995. Using the reliability diagram of Appendix A of Report G815, the reliability was predicted at 0.9977. Major contributors to system unreliability are the Electric Connector Lanyards (35 percent), the Bellows (35 percent), and the Thrusting Joints (17 percent).

The FMEA identified seven (7) single failure points for the Payload Shroud. In addition, nine (9) critical redundant backup components and three (3) launch critical components were identified. For the seven single failure point items, engineering rationale was established to justify to use of all items as designed.

Eight components were identified as Reliability Critical items. Significant characteristics were established for each item to aid inspection, and controls for the handling of all items were set forth in reports G2413 and E0365.

Reference: G815 Airlock Reliability Model, Appendix A

E0365 Airlock Module Critical Item List

G2413 Control Plan Reliability Critical Items

3.1.7.2 System Safety Engineering

Analysis of the non-metallic materials used in the Skylab I Payload Shroud (PS) to identify those which could have contributed to flammability or toxicity hazards was accomplished. The evaluation showed that the selected non-metallic materials were suitable for the design application.

In addition, a hazard list was provided, items of safety significance were identified, explosive components were monitored for safety, a safety analysis

of the ground support equipment was performed, and PS Safety Checklists were prepared.

Reference: G671 Airlock Safety Plan

3.1.7.3 Qualification Status

The Airlock Qualification Status Report (E935) has established the qualification status for twelve components of the PS. It was determined that eight components had been tested at the environmental levels specified for the PS. The remaining components were found acceptable on the basis of similarity to components used on previous programs where test levels were equal to or more severe than the PS requirements.

Reference: E935 Airlock Qualification Status Report

3.2 GROUND TESTING

3.2.1 Development Testing

Structural Panel Tests

The objectives of these tests were to (a) determine the load paths through the rail and adjacent structure, (b) verify the structural integrity of the rail and adjacent structure, and (c) determine the moment carrying capability across the rail separation joint. Two specimens were constructed to simulate a section of the separation rail mated on both sides to a flat skin panel and frame sections. Two tests were performed on the first specimen simulating hoop tension loading in the shroud. These tests showed that nearly all of the tension load is taken by the attachments in the outer flange. The second specimen was tested once under bending load representing in-plane frame bending. In this test the attachments failed in combined tension and shear. In order to account for this effect, a "prying" factor of 1.06 was derived from the test data for use in the analysis. In each test the rivets joining the separation rail halves satisfactorily failed in shear or combined shear and tension without damage to the specimen structure.

Reference: G0368 Airlock Payload Shroud Panel Structural Tests

Acoustical Panel Tests

In support of the preliminary noise reduction analysis, a panel test was conducted to determine the acoustic transmittivity of typical shroud structure. Tests were conducted on a bare panel and on a panel coated with thermal insulation. The tests was run in such a way as to provide the transmission loss of the panel.

Reference: TM-DM118-ENV-R6673 Acoustic Panel Development Test

EBW Detonator Confinement and Propagation Tests

The EBW detonator confinement and propagation tests were conducted to demonstrate that 1) the detonator will successfully initiate the thrusting joint linear explosive assembly with twice the maximum gap obtainable in flight hardware; 2) the detonator block with its internal volume reduced 10 percent successfully withstands and contains the explosion; 3) the linear explosive and detonator successfully functions after exposure to Skylab I vibration level requirements; and 4) the detonator block successfully withstands and contains the detonation products of a 9 strand linear explosive assembly. The only problem encountered during the tests was gas leakage at a union fitting. This problem was resolved with the insertion of a machined sleeve.

Reference: ACBO-TM0124 Skylab I Payload Shroud EBW Detonator Confinement and Propagation Test

Thrusting Joint Panel Separation Tests

Twenty development panel tests were conducted to finalize the design of the thrusting joint components and to provide margin data on the system. The bellows successfully contained the gas of nine strands of linear explosive and the system successfully demonstrated a force margin capability of two with a nominal seven strand charge. The attenuator tubes survived a nine strand test (129 percent nominal charge) demonstrating a satisfactory margin. Burst tests on the bellows provided data for the development of the final bellows configuration.

On tests numbers 18 and 19, the panel separation tests using a production type bellows, the bellows showed post-test damage. The investigation reported in ICWO Data Item 5.1, Failure Report Issue Number 1, revealed that there were two anomalies. The first involved incomplete curing of the rubber bellows,

as evidenced by the lower strength and toughness, and incomplete bonding of the rubber material with the woven fabric material. The second anomaly was caused by the high velocity particles from the linear explosive impacting the bellows directly opposite the outer attentuator tube holes. The incomplete curing was a manufacturing processing problem which was remedied by increasing the curing time and temperature. The problem of the leaks caused by the high velocity particles was eliminated by doubling the thickness of the rubber at the impact area. All subsequent test bellows and the production bellows incorporated these two changes.

Reference: ABCD-TM0120 Skylab I Payload Shroud Thrusting Joint Panel Separation Tests

Pin Puller Tests

Initial development tests were performed to provide data for the finalization of the design. Later evaluation tests were run to verify the adequacy of the pin puller system.

The development tests established the friction coefficient between the pin and link/clevis, provided data on the retainer washer performance, provided data for the crush block (energy absorber) design and established initial performance and margin data for the pin pullers.

The evaluation tests verified successful operation of the pin puller system under adverse conditions of vibration, temperature, and side loading. The evaluation tests also verified successful operation with the system loaded to 50 percent and 150 percent of the normal explosive charge and side loaded at zero to 333 percent of nominal side load. In Test No. 15 one of the four pin pullers failed to retract. That test was performed under margin conditions with 75 percent explosive charge and at -20°F. Investigation of the failure revealed that previous testing with the same hardware had removed the dry lubrication on the pin. The resulting increase in friction increased the required pull force to 112 percent (see Failure Report Data Item 5.1 Issue No. 3 dated 21 December 1970). During the final evaluation test, No. 16, one of the 90° bend transfer tubes burst. This test was at high temperature with 150 percent explosive charge and three pins side loaded to over three times

design load. The cause of the rupture was determined to be interaction of shock waves from two strands of the explosive charge in the tubing bends. See Failure Report Data Item 5.1, Issue No. 5, dated 10 September 1971. The tube rupture problem was resolved in conjunction with the post-Plum Brook No. 2 tube design change activity.

Reference: ACBD-TM0129 Skylab Payload Shroud Pin Puller Design Evaluation and Development Tests

3.2.2 Qualification Testing

Thrusting Joint Panel Separation Tests

Five qualification tests were successfully conducted utilizing the final configuration components. In Test No. 25 the panels separated successfully, but the outer side of the cylinder rail fractured along the line of the rivet pattern. Investigation of this incident was reported in Data Item 5.1, Failure Report Issue No. 2, dated 26 June 1970. The investigation's conclusion was that the unsymmetrical rivet pattern between the inboard and outboard sides of the cylinder rail resulted in a bending moment being applied during separation which caused a bending fracture along the outer side of the cylinder rail.

Subsequent to Test 25, the rivet pattern along the separation joint was changed to provide a symmetrical pattern along the inboard and outboard sides of the cylinder rail. This change resulted in an increase of the maximum average rivet strength along the separation joint from 2,100 pounds per inch to 2,600 pounds per inch. The development panel separation tests demonstrated the ability of the thrusting joint to shear 6,120 pounds per inch of rail. After the change in rivet pattern the available force is still in excess of the required twice the maximum average flight rivet configuration along the separation joint length. The symmetrical rivet pattern was incorporated into the full scale separation test specimen and flight units and was successfully demonstrated in the three full scale separation tests and the bellows preflight verification test.

Reference: ACBD-TM0120 Skylab I Payload Shroud Thrusting Joint Panel Separation Tests

Pin Puller System Tests

The pin puller system qualification test consisted of three test firings of three complete systems with flight configuration production hardware. Two test firings were performed at -20°F with all four pins side loaded to the design requirement of 15,000 pounds. The third test firing was performed at +160°F with two pins side loaded to 15,000 pounds and the other pins unloaded. An initial side load of 50,000 pounds was applied to each pin that was side loaded and then reduced to the 15,000 pound load and maintained during firing. All pin pullers were exposed to the flight level vibration environment before assembly into the system test setup.

Two anomalies occurred during testing; the pin puller mounting bolts failed during vibration and a B-nut leaked after the +160°F test. The bolt failure was determined to be caused by fatigue in that 8 bolts were used to mount 12 pin pullers in the vibration fixture. See Data Item 5.1, Failure Report Issue No. 8, dated November 8, 1971 for details. The B-nut leakage was due to low torque caused by torque relaxation. See Data Item 5.1 Failure Report Issue No. 9 dated December 6, 1971. The leakage of the B-nut during the qualification test was investigated in detail. The results, reported in TM0135 indicated that leakage was caused by B-nut torque relaxation. The tests provided data to indicate that higher torque values and multiple torque applications at lapse time intervals would provide post-fire residual torque levels well above that required to prevent leakage. New torque requirements, based upon the test results, were incorporated in the field station procedure for the flight hardware.

Reference: ACBO-TM0132 Payload Shroud Pin Puller Qualification Tests
ACBO-TM0135 Payload Shroud Latch Actuator B-Nut Leakage Investigation Report

Diode Module Test

The electrical system diode module, which is used in ground checkout, was originally designed as GSE and to be removed before flight. A decision was made to leave the modules installed during flight to eliminate the need for their on-pad removal. The modules are non-functional in flight. A vibration and shock qualification program was conducted to flight qualify the modules.

The module support bracket developed fatigue cracks during the initial vibration test. The brackets were changed to heavier gage sheet and the tests were successfully completed.

3.2.3 Verification Testing

Three full-scale separation tests, denoted as Plum Brook Firing No. 1, 2, and 3 (or PB-1, -2 and -3) were conducted by the NASA with MDAC support at the NASA Plum Brook Station, Sandusky, Ohio, from late 1970 through mid 1971. The test unit PS was completed, acceptance tested at MDAC-Huntington Beach, then disassembled into eight major components and transported by truck to Plum Brook.

The PS was reassembled and installed in the large Plum Brook Space Power Facility vacuum chamber for the firing demonstration tests. An arresting net system was installed to catch the jettisoned PS Quad-segments; they worked flawlessly during each of the tests. The PS separated successfully in all three tests and all testing was performed with the same PS; it was refurbished as required for each test sequence. Refurbishment consisted, in general, of replacing the separation system functional parts and incorporating the design changes that evolved during this phase of the program.

Several design problems were encountered during PB-1 and PB-2. Post-test inspection after PB-1 revealed the following discrepancies:

- Three damaged areas in one bellow unit. Each damaged area was a slit approximately 1/2 inch long.
- A considerable number of sheared rivets dislodged and scattered throughout the chamber.
- The nose cone/cylinder attach angle at the separation plane fractured during the separation event.
- The second frame aft of the nose cap interface fractured.
- Small cover plates at the nose cap/cone interface were slightly deformed.
- The base ring index pin was damaged during installation of the PS.
- One purge duct clamp liner disengaged.

These anomalies were investigated and results reported in Data Item 5.1, Failure Report Issue Number 4. The bellows damage was caused by a bellows installation procedural error. A detailed bellows installation procedure, 1B89567, was released to supplement the bellows installation drawing. The following design improvement changes were incorporated into the test unit prior to PB-2.

- o Retainers were installed to contain dislodged rail shear rivets.
- o Teflon covered spacer blocks were mounted on the nose cap frame in six places.
- o Damaged portions of the cone base ring attach angles were replaced and the heat treat condition of the cone base ring was changed from T6 to T73. External reinforcement fittings were added.
- o A reinforcing member was added to the splice of the nose cone ring to separation rail.
- o The clocking pin for the Cylinder to FAS alignment was reinstalled and the GSE Alignment Kit was used to assure the pin was centered in the groove.
- o The bellows filler spacing was decreased to improve the bellows retainer wire installation.

Plum Brook Firing No. 2 was conducted on the refurbished PS and the separation event was again successful. Post-test inspection after PB-2 revealed two minor problems and one rather major problem. Data Item 5.1, Failure Report No. 6 reports the action taken to fix the first two problems. The nose cone teflon slide block was changed to nylon to improve its abrasion resistance and a structural reinforcement was added to a nose cone frame.

The major problem encountered was that two 1B83259-1 Transfer Tubes and two 1B83260-1 Transfer Tubes of the thrusting joint system were found to be ruptured. The ruptures occurred at the first major bend close to the detonator block. The four tube ruptures experienced during this test as well as the tube rupture that occurred during the pin puller margin evaluation test resulted in an investigation into the cause of the rupture. According to the investigation, reference Data Item 5.1, Failure Report Issue Number 7, the failure was initiated by scoring of the interior of the tubes by the interacting detonation

shock waves of adjacent strands of linear explosive. Detonation gas pressure then ruptured the tubes along the scored surface. The transfer tube system was redesigned to eliminate the possibility of another failure. Two design fixes were evaluated; one was to increase tube diameter and wall thickness to withstand the combination of scoring and high pressure. The other was to insert a liner inside the tube to eliminate scoring. The final redesign incorporated both thicker walls and a polyethylene liner in the transfer tubes.

Sixteen tests were conducted prior to PB-3 to verify the integrity of the redesigned transfer tubes. The test utilized a test specimen which simulated the transfer tube from the detonator block to the thrusting joint attenuator tube and results are reported in Report A3-250-ACBO-TM0131.

The test specimen for PB-3 incorporated the following design changes which were also incorporated into the flight production Payload Shroud:

- Attentuator tube bends were eliminated and replaced with machined elbow assemblies and redesigned transfer tubes.
- The pin puller tubing system was re-routed to minimize the number of bends and the remaining small radii tube bends were redesigned to strengthen the tubes and add polyethylene liners.
- Purge duct support brackets were modified to allow for clearance of a redesigned and rerouted pin puller tubing system.
- A new tube cleaning process, STP 0407-01, was implemented on the pin puller and thrusting joint tubing system. X-ray inspection was added to verify cleanliness of the attenuator tubes.
- Purge duct diameter was increased with tape buildup in the clamp areas to provide better clamping.
- An index lug was added to the attenuator tube assembly to provide index reference of the tube for proper hole orientation after assembly. Redesign of the attenuator tubes in the cylinder section removed all orientation reference bends.
- The EBW firing units, pulse sensors and associated wiring for the Pin Puller Systems were relocated to accommodate the redesign and rerouting of the pin puller tubing.

The third separation test was conducted and was completely successful. The complete Plum Brook testing is reported in A3-250-ACBO-TM0139.

After PB-3, Quadrant IV of the Payload Shroud was refurbished with new thrusting joint and pin puller systems components and linear explosive assemblies. The remaining quadrants were assembled with expended hardware. The entire Payload Shroud was transported to JSC and then subjected to the predicted flight vibroacoustic environment. The pin puller system on Quadrant IV was successfully functioned after exposure to the JSC testing. Results of the test are reported in Report A3-250-ACBO-TM0139. The tubing system integgity of both the pin puller and thrusting joint were verified by leak checks after both vibration and acoustic testing. The pin puller tubing system was also checked after functioning. No design problems were encountered during or after this test. The thrusting joint linear explosive assembly subjected to the vibroacoustic environment was removed from its installation and successfully completed a special functional integrity verification test (A3-250-ACBO-TM0140).

Reference:	ACBO-TM0130	Skylab I Payload Shroud Full Scale Separation Plum Brook Tests 1, 2, and 3
	ACBO-TM0131	Skylab Payload Shroud Transfer Tube Redesign Verification Tests
	ACBO-TM0139	Skylab I Payload Shroud Vibroacoustic Test, Pin Puller Verification
	ACBO-TM0140	Houston Primaline Tests

3.2.4 Special Verification Tests

Vibro-Acoustic Tests

The actual internal acoustic levels for the shroud when exposed to the external launch environments were measured during the full scale stack test run at the Johnson Spacecraft Center (JSC). The noise reduction measured during the full scale test showed the estimated noise reduction of the shroud to be accurate. The levels measured inside the shroud were less than the specification requirement.

Acceleration measurements were made on the shroud during the full scale acoustic test at JSC. The random vibration levels measured on the shroud were lower than the predicted levels except for the skin measurements in the frequency range from 150 to 200 Hz. These levels exceeded the design criteria which were based on predicted levels. The Airlock Environmental Design Requirements, Report F319, were modified to take into account these higher levels. Affected equipment components were re-evaluated in light of the revised higher levels and appropriate action was taken.

Linear Explosive Thermal Conditioning Verification

All of the explosive assemblies initially received at KSC for the flight Payload Shroud were found to be short during receiving inspection. The results of the ensuing investigation and of the verification tests of the redesigned assemblies are reported in Report A3-250-ACBO-TM0152.

Shrinkage tests were conducted subjecting several lengths of detonating fuse which were unspooled directly from the suppliers shipping spools to various temperatures and for various time-periods to determine their shrinkage. The resulting data showed that shrinkage rate increased with increased temperature and diminished with time. This property enhanced the practicality of pre-shrinking detonating fuse by means of a heat soak.

To provide design verification of flight configuration Linear Explosive Assemblies that have been thermally preconditioned and subjected to the temperature controls, two long term shrinkage and tension tests were conducted. The shrinkage test verified that a thermally conditioned harness does not shrink significantly after installation in a flight configuration tubing system. The tension test verified that the shrinkage of a thermally conditioned harness will not produce tension loads on the end caps in excess of the allowable pull load of 11 pounds.

Reference: ACBO-TM0152 Skylab Payload Explosive Cord Shrinkage Investigation

Bellows Verification

A preflight verification test was successfully conducted on a section of thrusting joint representative of the flight hardware to verify that the installation was not age-sensitive. The test specimen was a rail assembly from the PS Separation Test Unit refurbished at approximately the same time as PS Flight Units Nos. 1 and 2 were assembled. The test specimen was shipped from Plum Brook to Houston, exposed to the vibro-acoustic test environments then shipped to MDAC Santa Monica for the preflight bellows verification.

Reference: ACBO-TM0147 Payload Shroud Preflight Verification Test

3.3 DESIGN REVIEWS

3.3.1 Preliminary Design Review

The Preliminary Design Review (PDR) was held as part of the Cluster Systems Design Review (CSDR) on December 2, 3, and 4, 1969. This was the first design review conducted subsequent to the CCP No. 49 design approach studies. The PS review charts are included in the MDAC Data Package, Structural/Mechanical dated 13 November 1969. The design configuration at this time was essentially the same as that proposed by the CCP. The PS configuration, subsystem functions, materials usage, and preliminary design verification analyses were reviewed. One PS action item was established: MDAC was to re-evaluate use of 7075 aluminum alloy in the T6 temper as proposed for several of the structural parts. The action was completed by establishing a design policy to minimize the use of 7075-T6 and revise the drawings to use 7075-T73 instead where practical (Ref. TTM SSP-012, dated 12 December 1969).

3.3.2 Critical Design Review

The Critical Design Review (CDR) was held 10 August 1970. The design configuration reviewed was that of the test unit PS (S/N 000001) which was then essentially complete. Significant design changes subsequent to CDR were skin-thickness changes on the forward nose (change from a modified type 203 nose to new MDAC design) and a change of the discrete latch ordnance system approach (change from an EBW gas cartridge system to a linear-explosive integrated pressure system). Two (2) payload shroud Review Item Discrepancies (RID's)

were generated which requested added system acceptance testing. These RID's were closed by MDAC with the NASA's concurrence, after a review which established the existing program to be adequate.

3.3.3 Critical Mechanisms Review

In November of 1970, the Orbiting Astronomical Observatory (OAO-B) spacecraft was launched from KSC on an Atlas Centaur vehicle. The spacecraft failed to reach orbit due to failure of the General Dynamics/Convair (GD/C) shroud used on the Atlas Centaur to completely jettison. As a result of this failure, the Skylab Program Office decided to conduct special reviews of all Skylab Cluster deployment mechanisms that were critical to mission success. The complete PS was reviewed as a critical mechanism as a line item phase of the CMR. A viewgraph presentation on the PS was prepared and given at MSFC on 18 and 19 August 1971.

The review included a re-examination of the basic requirements on which the PS design was based, and a general review of the overall PS configuration with particular emphasis on weights, cleaning and sealing.

Details of the various critical subsystems, which together provide the composite PS operational system were reviewed in depth. Particular emphasis was placed on the following:

- FAS to Payload Shroud interface including the tension cleats.
- The anti-clocking pin, and the aft frame splice.
- ATM Support structure interface.
- Thrusting joint design details, including descriptions of the bellows, EBW detonator, detonator block, attenuator tubes, end seals, linear explosive and transfer tubes. Emphasis was given to the various design changes which were incorporated as a result of transfer tube rupture anomalies experienced during the full scale separation tests.
- Pin puller (discrete latch) system including an overall description, analysis of loads and force margin.
- Air conditioning duct configuration and routing.
- Electrical lanyard disconnect system.

A section of the review provided a detail description of the electronic functional and operational sequence logic used to achieve PS jettison. Also reviewed were the FMEA and SPF analyses and status, the ground test program results and status, and the quality assurance program and status.

The Critical Mechanism Review resulted in 13 action items all of which were satisfactorily responded to per MDAC-E Letter 646-E450-830. The action items are listed below:

- o Definition of controls employed to preclude use of "over-strength rivets".
- o Review of compatibility of bellows material with cleaning solvent.
- o Review of techniques employed to install the bellows.
- o Possible outgassing of material used in the air conditioning duct separation seal.
- o Compatibility of payload shroud dynamic envelope with the payload.
- o Addition of an electrical harness length check at KSC.
- o Rationale for Primaline pull testing.
- o Review of pin puller system vibration testing.
- o Effects of launching with one pin puller retracted.
- o Differences between flight hardware and hardware used during full scale separation test.
- o Details of separation dynamics (piston and cylinder time/displacement characteristics).
- o Development test report data package.
- o Analysis of jettison motion with particular emphasis on amount of rotary motion superimposed on the translatory motion.

3.3.4 Systems/Operations Compatibility Assessment Review

The Skylab Systems/Operations Compatibility Assessment Review (SOCAR) consisted of a series of reviews at MSFC, JSC, and MDAC-Huntington Beach between December 1971 and June 1972. Review participants include MSFC, JSC, and the Skylab Module Contractors. The primary objectives of the SOCAR were to assess the Skylab Systems design integration and to assess the operational readiness of the Skylab through a detailed review of the mission documentation, plans and techniques to be used for conduct of the mission. The SOCAR verified that JSC

mission operational documents were compatible with the PS design, and verified adequacy of PS test schedules, plans, and objectives. No PS action items resulted from the SOCAR.

3.3.5 Design Certification Review

The Design Certification Review (DCR) was held in phases during the time period May through October 1972. The DCR examined design performance and verification status of the major Skylab contract end items, the significant crew and experiment interfaces, and mission operations activity. Specifically, as pertinent to the PS, the Skylab DCR was conducted to assess and certify the adequacy of the performance design requirements and verification programs of the end items and their interfaces as a complete space vehicle system for flight worthiness and manned flight safety. The initial DCR for MSFC assessment of suitability for certification was held 22 to 24 May 1972 at MDAC-E, and the final DCR to the Skylab Management Council was held 2 October 1972 at MSFC. No PS action items resulted from the DCR.

Section 4

HARDWARE VERIFICATION PROGRAM

The hardware verification program consisted of fabricating the PS hardware in conformance with the design configuration developed by Part I and Part II of CEI Specification E0047--including design approaches verified by the Design and Development Test Program (E0041), implementing the Quality Assurance Program in accordance with Plan E854, acceptance testing in accordance with Plan E0042, conducting acceptance reviews in accordance with the Airlock Contract Statement of Work and supporting a special NASA Hardware Integrity Review. A Reliability Critical Item Program was set-up to control critical Skylab PS equipment in accordance with Plan G2413.

Throughout fabrication and assembly, both at supplier's and at MDAC facilities, hardware verification of materials, configuration, cleanliness and function was accomplished. These procedures were implemented by the normal MDAC system utilizing Fabrication Orders and Assembly Outlines. Documentation of completed procedures are maintained in the MDAC Quality Data Files.

Reference: E0041 PS Development and Qualification Test Plan
E0042 PS Acceptance Test Plan
E854 Quality Assurance Provision Plan
G2413 Reliability Critical Items Control Plan

4.1 ACCEPTANCE & SYSTEM CHECKOUT TESTS

4.1.1 Weight and Center of Gravity

The weight and longitudinal center of gravity measurement procedure for the PS is specified in 1B82405. This document is also used to record weight and center of gravity data as measured. These data are corrected to launch weight in Report G0178.

Reference: G0178 Mass Properties Status Report

4.1.2 Tube Bellows

Acceptance tests on the separation tube bellows were conducted by cutting specimens from each end of the production bellows and subjecting these specimens to burst pressure, proof pressure and leakage tests. Tests were conducted to the requirements of Dwg. 1B84171 and to the procedures of 1B84171-PATP1.

4.1.3 Bellows Installation

A proof pressure test and four leakage tests were conducted at various stages during and upon completion of the bellows installation into the Payload Shroud. Tests were conducted to the requirements of Drawing 1D15754 and per the procedures of 1D15754-PATP1.

4.1.4 Linear Explosive Assembly

Acceptance tests for the 1D15820 Linear Explosive Assembly and the 1B82675 Latch Linear Explosive Assembly are specified in Drawing 1D15826. These tests include end caps tensile tests, visual inspection, radiographic inspection (both X-ray and neutron radiography) and a lot verification test firing. Verification firing tests for Payload Shroud S/N 000003 (Flight Unit No. 1) were conducted at KSC in conjunction with the installation of the Linear Explosive Assemblies into the Payload Shroud.

4.1.5 Electrical Installation

The Payload Shroud Electrical Installation, Drawing 1D15752, was acceptance tested to the requirements of Drawing 1D16202 and per the procedures of 1D16202-PATP1 and 1B90686. The Payload Shroud instrumentation installation was acceptance tested to the requirements of Drawing 1B87528 and to the procedures of 1B87528-PATP1. These tests were conducted on Flight Unit No. 1 prior to delivery of the Payload Shroud to KSC and were repeated during checkout at KSC. In the case of Flight Unit No. 2, the acceptance test was conducted prior to placement of the unit in storage and will be repeated at KSC upon reactivation of the unit. The electrical system end-to-end system tests accomplish the following verifications:

- o Pulse sensor circuits.
- o ATM deploy inhibit circuits, continuity and simulated separation.
- o Separation talk-back circuits, continuity and simulated separation.
- o Discrete latch and longitudinal separation joint circuits.

- Accelerometer and acoustic circuits
- Mating and separation force of lanyard disconnect interface connector.

4.1.6 Cylinder Assembly

The cylinder assembly test requirements are outlined in Drawings 1D15749 and 1D15702. Tests verify, by inspection of physical dimensions, the PS/ATM and PS/FAS interface.

4.1.7 EBW Detonators

The EBW detonators were GFE. Lot acceptance test documentation was supplied with the detonators at KSC for Flight Unit No. 1. The same procedure will be followed for Flight Unit No. 2.

4.1.8 EBW Firing Unit

The EBW firing units were GFE. They were acceptance tested per NASA Specification 40M39515B, paragraph 4.5.3 and MDAC Drawing 1A18772.

4.1.9 Discrete Latch Pin

The PS explosive installation drawing (1B60683) and the explosive installation handling and checkout drawings (1B84998 and 1B85392) include requirements for the discrete latch actuator installation. These requirements were designed to assure that the force required for movement of the latch pin does not exceed the allowable pre-load requirements. The procedure to confirm compliance with this requirement was performed at KSC per KSC Report KS-1002. A prior test was conducted at MDAC-W using similar shipping pins in lieu of the latch actuator. In addition, at the component level, the freedom of motion of each latch actuator was verified upon its assembly.

4.1.10 Preparation for Shipment

Cleanliness acceptance requirements are denoted on Drawing 1D15700 and defined by STP0407-01. Packaging requirements are as defined by STP 0408-01 and noted on Drawing 1D15700. The process requirement documents implement, in part, Contamination Control Plan E0466.

Reference: E0466 PS Contamination Control Plan

4.2 ACCEPTANCE REVIEWS

Prior to the delivery of each unit, a Payload Shroud Acceptance Review was held. Representatives of NASA, U. S. Air Force, MDAC-East and MDAC-West participated. These reviews were held primarily for the purpose of assuring that all facets of the program were properly handled and documented, to respond to any questions of the participants, and to make any changes or adjustments required for completion and signing of the DD-250 and the Certificate of Flight Worthiness (COFW).

4.2.1 Payload Shroud S/N 000001 (Full-Scale Separation Test Article)

The Acceptance Review of Payload Shroud S/N 000001 was held at MDAC Huntington Beach, on 1 October 1970. The purpose of this meeting was to review the scope and content of the Acceptance Review Data Package and to effect an orderly and timely "turnover" of the Payload Shroud to the Customer. For this review, a representative of the NASA Plum Brook facility was present in order to discuss matters pertaining to the forthcoming separation tests of the Payload Shroud at that facility. Several action items were generated during this review; they were answered and closed to complete the review.

The DD-250 for Payload Shroud S/N 000001 was signed on 17 October 1970, and the unit was shipped to the NASA Plum Brook facility on 20 October 1970. A Certificate of Flight Worthiness was not required for this test unit.

4.2.2 Payload Shroud S/N 000003 (Flight Unit No. 1)

Three separate Acceptance Reviews were conducted for this unit. The first, an informal pre-acceptance review, was held on 19 January 1972, at MDAC Huntington Beach. This review was attended by NASA, Air Force, MDAC-East and MDAC-West personnel for the purpose of resolving problems and clarifying actions required in preparation for the acceptance review.

The Acceptance Review was held and completed on 31 January 1972. The DD-250 and Endorsement One of the Certificate of Flight Worthiness (COFW) were completed and signed on 4 February 1972.

The DD-250, signed on 4 February 1972, contained open assembly items and added tasks to be accomplished prior to delivery of the unit to KSC. Thus, a

Supplemental Acceptance Review was held at MDAC-West, Huntington Beach, on 10 August 1972. Five policy type action items were generated during this review with action responsibility assigned to NASA, USAF and MDAC. They were satisfactorily resolved and closed subsequent to the meeting. Endorsements One and Two of the Certificate of Flight Worthiness were completed and signed this date. It was agreed during the review that the DD-250 would be signed just prior to the Payload Shroud leaving the MDAC-West facility at Huntington Beach for transport to the USNS Point Barrow for shipment to KSC. The DD-250 was signed, as agreed, on 31 August 1972.

4.2.3 Payload Shroud S/N 000002 (Flight Unit No. 2)

Three separate Acceptance Reviews were held for Payload Shroud S/N 000002. The first of these was an informal pre-acceptance review held at MDAC-West, Huntington Beach, on 26 through 29 July 1971.

The Acceptance Review was held at MDAC-West, Huntington Beach, on 14 September 1971. Several action items were generated during this review with responsibilities for resolution assigned to NASA and MDAC as applicable. These items were subsequently resolved and the DD-250 was signed on 22 September 1971. The Certificate of Flight Worthiness, Endorsement One, was signed on 30 September 1971, as was Section A of Endorsement Two.

Because the DD-250 was signed with open paper and additional tasks to be accomplished, a Supplemental Acceptance Review was held and completed at MDAC Huntington Beach, on 1 February 1973. The DD-250 and the Certificate of Flight Worthiness were completed and signed.

4.3 HARDWARE INTEGRITY REVIEW

Skylab module contractors were requested by NASA on March 9, 1973 to conduct a comprehensive review of all Skylab Cluster critical activation sequence hardware. Fifty-three critical sequences were tabulated for review, and PS jettison was denoted as Sequence No. 11. The PS critical sequence was reviewed as part of the AM critical sequence review on 22 through 24 March 1973.

The review activity began immediately following the March 9 turn-on with Contractor/MSFC-S&E technical teams set-up in the various contractor's plants

to assemble a survey package for each critical component of each activation sequence. The survey package contained technical and fabrication records, qualification and acceptance test history, and traceability data on each component.

Payload Shroud items of particular interest during this review were the Lanyard Disconnect Electrical Connector, the Payload Shroud Tubing Installation, the Linear Explosive Assemblies, the Discrete Latch Assembly, the Bellows Tube and Installation, the Attenuator Tube Assemblies, the EBW Detonators and the EBW Firing Units.

The objective of the review was to systematically resurvey--against a comprehensive set of check lists--the hardware items for design, qualification, fabrication, acceptance test, and field test adequacy. The PS review was satisfactorily completed and no added action was required.

Section 5

HANDLING TRANSPORTATION AND STORAGE

MDAC utilized existing Government Furnished Equipment, modified other GFE, and designed new Ground Support Equipment to support the handling, transportation and preparation of the Payload Shroud for its mission. The equipment is also utilized to support the PS in the storage mode. The Payload Shroud GSE consists of three categories:

- Mechanical Ground Support Equipment (MGSE)
- Electrical Ground Support Equipment (EGSE)
- Handling and Transportation Equipment (HTE)

These equipment were utilized to support in-factory operations, transportation and storage, and KSC operations.

5.1 MECHANICAL GROUND SUPPORT EQUIPMENT

The Payload Shroud MGSE is listed in Table 5.1-1. The MGSE includes the DA-118-4 Cover Kit and the DA-118-26 Cover Kit which provides protection of the PS from the elements during over-the-road and barge transportation. The DA-118-8 Access Kit provides access to the cone/cylinder joint area for PS mating and arming operations. The DA-118-16 Explosive Handling Kit provides storage for and supports the installation of the separation and latch actuator system linear explosive assemblies in the PS. It consists of two suitcase-size carrying case assemblies that include holding spools for the explosive assembly storage and handling operations. The DA-118-17 Pin Puller Kit is a hydraulically actuated ram plus adapters, which provides the means for removal of the shipping pins and installation of the flight discrete latch actuators. The DA-118-24 Storage and Shipping Kit provides attachments, filters and desiccant devices to maintain the required humidity and cleanliness levels

Table 5.1-1

MECHANICAL GROUND SUPPORT LOUIPMENT

Model No.	Part No.	Title	Applicable H & CO
DA-118-4	1D15766-1	Cover Kit, Shipping	1D16288
DA-118-8	1D15770-1	Access Kit, Cylindrical Section	1D16292
DA-118-9	1D15771-1	Access Kit, Forward Cone	1D16293
DA-118-16	1B84699-1	Handling Kit, Linear Explosive	[illegible]
DA-113-17	1B85005-1	Pin Puller Kit	[illegible]
DA-118-24	1B89889-1	Storage and Shipping Kit	[illegible] Storage [illegible] Shipping
DA-118-25	1B91209-1	Accessories Kit, Wire Protection	[illegible]
DA-118-26	1B91501-1	Cover Kit, Protection	[illegible]
DA-118-29	1B93140-1	Repair Kit, Protective Cover	1B93142
DA-118-30	1B94407-1	Protection Kit, Pin Puller Tubing	1B94406
DSV-4B-305	1A57863-1	Tool Kit, Special	--
DSV-4B-450	1B57000-1	Desiccant Kit, Static, S-IVB Stage	--
HC-500EA	44013160	Dehumidifier	--

230.6

during PS storage and shipment. The DA-118-25 Wire Protection Kit includes bracket plate assemblies that cover the electrical wiring in critical areas and thus protects the cordage during PS ground operation activities.

5.2 ELECTRICAL GROUND SUPPORT EQUIPMENT

Table 5.2-1 lists the EGSE. The EGSE includes the DA-118-15 Electrical Checkout Kit which consists of pulse sensors on brackets that are mounted in the PS during ground checkout of the electrical system. A DA-118-21 Electrical System Checkout Kit provides the power to, and monitors signals from, the DA-118-15 Checkout Kit during the ground checkout operations. Miscellaneous electrical test equipment includes the EBW Firing Unit and Initiator Test Sets (Part Nos. 5886383-1 and 5866051-1) which provide the necessary combinations of voltages, loads, and monitoring provisions to completely check out the Firing Units and Initiators. The stray Voltage Test Set, Part No. 1A80349-1, is a suitcase size test set used to verify a safe condition prior to connecting the electrical connectors to the EBW initiators.

5.3 HANDLING AND TRANSPORTATION EQUIPMENT

The Payload Shroud HTE is tabulated in Table 5.3-1. The HTE includes the DA-118-2/2A Handling Kits (Rings) which provide attachment and support to the PS for hoisting, handling and shipping. The DA-118-3 and -12A/12B Hoisting Kits (slings) are provided to handle the PS in conjunction with the -2/2A Rings and the PS Nose Cone alone during mating operations. A DA-118-22 Cradle Kit interfaces with the -2/2A Rings and provides interim horizontal support during weight and CG determination and installation of shipping covers. The Cradle Kit also supports the PS during over-the-road and sea transportation. The DA-118-23 Dolly interfaces with the Cradle Kit and provides for over-the-road transport.

5.4 TRANSPORTATION AND STORAGE

The transportation and storage of the Payload Shroud flight and test units were accomplished as shown on Figure 5.4-1 and Transportability Report G1020.

Table 5.2-1

ELECTRICAL GROUND SUPPORT EQUIPMENT

Model No.	Part No.	Title	Applicable H & CO
DA-118-15	1B83791-1	Checkout Kit, Electrical	1D16203
DA-118-21	1B88802-1	Checkout Kit, Electrical System	1D16203
—	5886383-1	Test Set, EBW Firing Unit	—
—	5866057-1	Test Set, EBW Initiator	—
—	1A80349-1	Test Set, Stray Voltage	—

Table 5.3-1

HANDLING AND TRANSPORTATION EQUIPMENT

Model No.	Part No.	Title	Applicable H & CO
DA-118-2	1D15764-1	Handling Kit, Payload Shroud	1D16286
DA-118-2A	1D15764-501	Handling Kit, Payload Shroud	1D16286
DA-118-3	1D15765-1	Hoisting Kit, Payload Shroud	1D16287
DA-118-5	1D15767-1	Support Kit, Payload Shroud Vertical	1D16289
DA-118-11	1B79759-1	Shipping Kit, Structural Test	1B79764
DA-118-12	1B80624-1	Hoisting Kit, Nose Cone, Test Unit	1B82762
DA-118-12A	1B80624-501	Hoisting Kit, Nose Cone, JSC	1B82762
DA-118-12B	1B80624-503	Hoisting Kit, Nose Cone	1B82762
DA-118-13	1B80625-1	Transporter Kit, Nose Cone	1B84168
DA-118-19	1B85587-1	Guide Pin Kit, Payload Shroud	1B85621
DA-118-22	1B89887-1	Cradle Kit, Payload Shroud	--
DA-118-23	1B89888-1	Dolly, Transporter, Payload Shroud	1B91232
DA-118-27	1B84195-1	Transporter, Nose Cone	--
DA-118-31	1B94934-1	Hoist Kit, Cylinder, Payload Shroud	1B94933
DA-118-32	1B95385	Storage Kit, Linear Explosive	1B95386

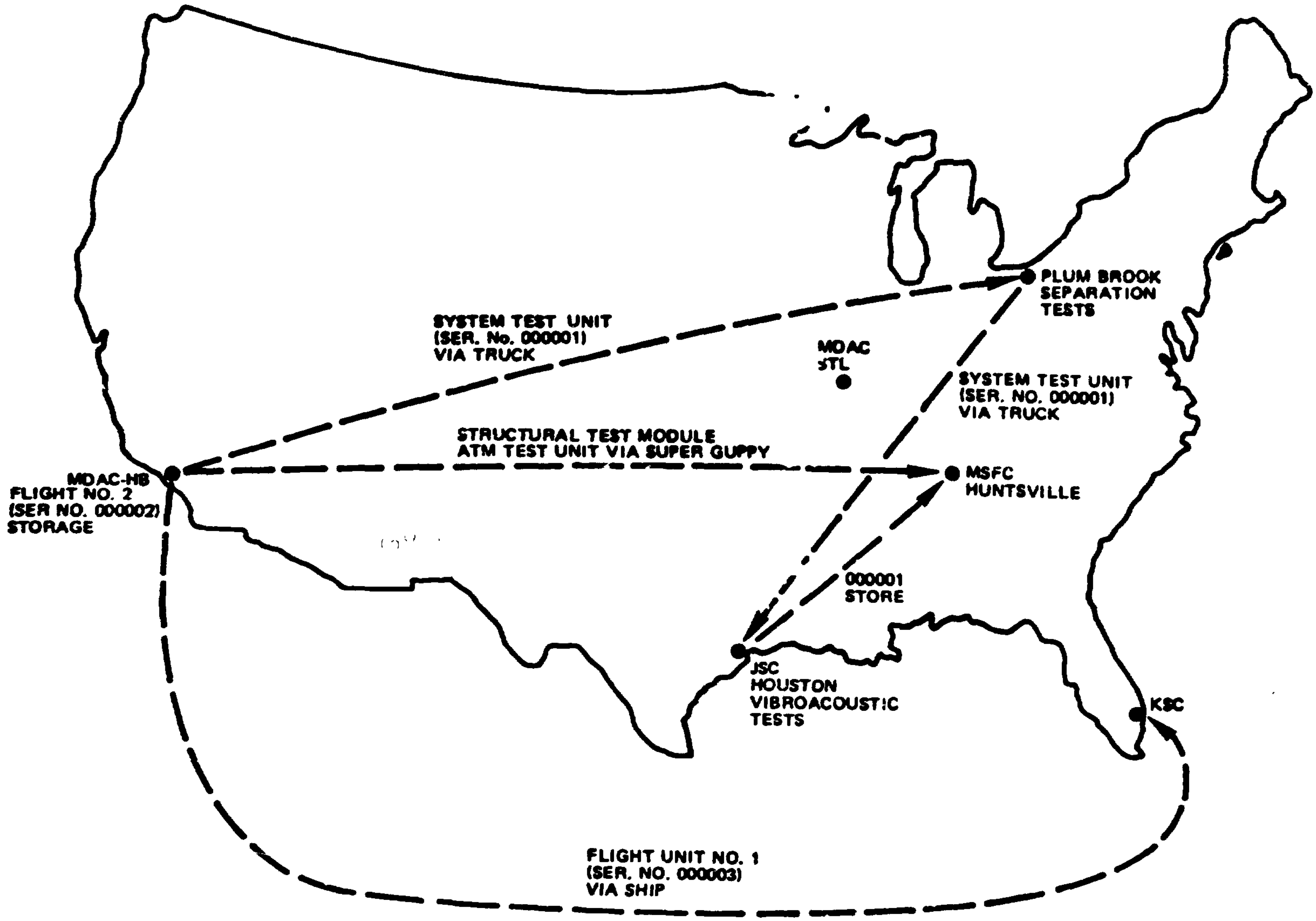


Figure 5.4-1. Skylab Payload Shroud Transportation Schematic

The System Test Unit (Serial No. 000001) was transported in 8 sections via highway from Huntington Beach (HB) to Plumbrook, Ohio, Plumbrook to Johnson Space Center (JSC) and from JSC to Marshall Space Flight Center (MSFC).

The Structural Test Module (ATM Test Unit) was transported as one assembly via air, using the super Guppy, from HB to MSFC.

The first flight unit (Serial No. 000003) was transported as a complete assembly via water from Seal Beach docks to Port Canaveral docks.

The second flight unit (Serial No. 000002) is presently in storage at Huntington Beach, and is maintained under controlled environmental conditions.

References: G1020 Transportability Report Airlock Payload Shroud

5.5 GSE MAINTENANCE PROGRAM

The GSE is being maintained in accordance with the Drawing 1B92569 program requirements. Twenty-four Maintenance Procedure drawings were prepared for PS equipment.

Section 6
FLIGHT TEST

Payload Shroud Flight Unit No. 1 was loaded on the USNS Point Barrow the morning of 7 September 1972 at Seal Beach, California. The ship was 15 days enroute to Port Canaveral, Florida. The GSE required for KSC operations had either been sent ahead to KSC by ground transportation, or was sent along with the PS on the ship. Payload Shroud ordnance were shipped directly from the ordnance manufacturers or as GSE and installed at KSC at proper times during the vehicle preparation activity. KSC Operations included performing receiving inspection of AVE and GSE, installing the Discrete Latch System LEA's in the PS Cylinder, installing the Thrusting Joint LEA's in the Nose Cone and Cylinder, installing the Cone and Cylinder on the vehicle, and conducting electrical and ordnance system checkout tests.

The PS was delivered to KSC in essentially a flight-ready configuration. There were a few minor open items on the PS at time of delivery and these items of planned work were completed at KSC. Modification to incorporate subsequent engineering changes were accomplished using a Modification Kit and Modification Instruction (MI) procedure. In this procedure, a complete package of design engineering and planning paper was assembled along with the required hardware items to comprise the Modification Kit. The work to apply a flat black finish on one of the ATM support fittings and the change-out of the diode module bracket are examples of MI activity accomplished at KSC.

There were two significant anomalies that occurred on PS hardware during KSC operations. The first problem, occurring during initial KSC operations, involved the Linear Explosive Assemblies. During receiving inspection of 22 assemblies, 8 for the thrusting joint system and 14 for the latch actuator system, all were found to be short. All 22 assemblies were rejected and the engineering investigation described in paragraph 3.2.4 was conducted to determine the cause of the problem. A complete replacement set of LEA's were made. A thermal conditioning operation was added to the LEA fabrication sequence,

and the assemblies were shipped to KSC in controlled temperature packaging (0°F to 50°F). The DA-118-32 Linear Explosive Storage Kit was added to the HTE to provide controlled storage of the LEA's during the storage mode at KSC.

On April 26, 1973, while the Skylab 1 was on-pad at Complex 39A, the vehicle was subjected to a rain storm accompanied by high winds. Subsequent inspection of the interior of the PS revealed that some rainwater had penetrated the PS and settled on a temporary tarp-type covering over the ATM sunshield. There was also some water on the cover just above the Level 4 platform, and at the base of the PS Cylinder near the FAS interface. The PS was designed to be rain-proof; the separation joint seams and the cone-cylinder field joint were sealed with beads of DC-140 sealant. The external paint finish was intended to be the sealant over fixed structural joints such as panel skin splices. The location of the water on the ATM cover indicated that the nose cap separation joint was probably not completely sealed and was leaking. Review of the fabrication techniques used to apply the sealant indicated that the material was not applied to the seam underneath the cap-cone support fittings in Quad III of the PS. A design change was made to repair the cap region using added DC-140 sealant on external nose cap seams and joints. It was not possible to repair other leak areas due to accessibility problems. The repair was accomplished on 10 May 1973 by the Boeing High Bay Crew using a rather spectacular technique; the crew "walked" the Damper Arms to gain access to the PS nose cap. A rain test, conducted the day after the repair indicated the cap repair was successful. The PS still had some leaks at the inaccessible seams, however, and it is evident that added rainproofing is needed on Flight Unit No. 2.

The launch of Skylab 1 took place 1:30 PM EDT, 14 May 1973. The discrete latch system was activated at 13:12 min:sec and, after verification that the system had functioned, the PS was jettisoned at 15:18 min:sec into flight. Flight instrumentation verified that all EBW circuits had functioned properly and the electrical umbilical connectors separated correctly. The PS was jettisoned in orbit when the Saturn Workshop (SWS) was in the nose down, gravity gradient attitude as shown in Figure 6-1. The resulting PS Quad-segment trajectories are such that in-orbital recontact with the SWS was precluded. Separation velocity of the PS Quad-segments has been determined from

the radar tracking records to be approximately 17 ft/sec, which agrees with the calculated and Plum Brook test values.

Data available from the acoustic measurement indicates the PS acoustic attenuation performance was actually better than calculated. The data available is furnished in a pressure spectrum and the analysis is by 1/3 octave band levels, thus, predicted and measured levels cannot be compared directly. However, comparison of the overall sound pressure level is meaningful; the predicted liftoff level was 138.5 dB and 132.1 dB was measured at launch. The predicted transonic level was 135 dB and 112.8 dB was measured during flight.

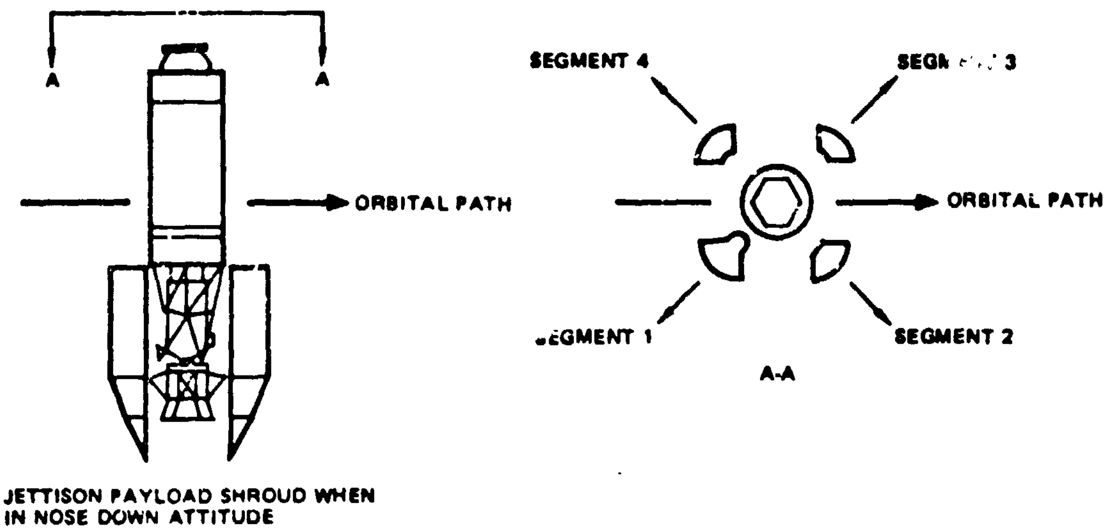


Figure 6-1. Payload Shroud Jettison Attitude

Section 7
RECOMMENDATIONS AND CONCLUSIONS

The Payload Shroud performance was demonstrated by Skylab I flight to be eminently successful. Flight Unit No. 1, in its final configuration, was essentially the same as that developed during the preliminary design effort conducted almost four years earlier. The decisions to use existing GSE, and Mainline Saturn tooling and workstands with minimal modification proved to be very cost-effective. Also the airborne hardware design decisions to utilize a simple, state of the art design approach, resulted in significant manufacturing cost-savings during the fabrication activity. The large structural factors of safety selected for structural design, in addition to eliminating the need for full-scale structural testing, allowed the design to contain less sophisticated parts and fastener patterns, hence, the spin-off fabrication cost savings.

The integration of the Payload Shroud activity into the Airlock Project proved to be effective from a Program Management standpoint. All PS technical interfaces were well defined early in the program and were, in the main, contained within the overall MDAC design responsibility. While the PS did directly interface with the ATM, structural connection was simple and straightforward. The automatic ATM release was effected by the accurately predicted motions of the PS quad-sections during the jettison event. The disengagement from the FAS was also simple and straightforward.

There are several technical findings that were discovered during the program that may prove useful during future payload shroud design activity. Below are listed, for future consideration, certain technical recommendations and conclusions resulting from the PS design, development and flight program.

RECOMMENDATIONS & CONCLUSIONS

Separation System

The ordnance actuated, contamination free thrusting joint concept and the ordnance actuated pin puller design developed for Skylab have proven versatile and adaptable in many sizes and configurations of separation and jettison devices. It is recommended that these concepts be seriously considered for similar future applications.

Linear Explosives

Linear explosives in multiple strand, multiple detonator applications are considered to be inherently reliable. However in long lengths a shrinkage problem with the detonating cord used as a component of the linear explosive assembly was encountered. This problem was resolved by a pre-conditioning and environmental control method. For future design, addition of adjustable length tubes, or adjustable locations of detonator blocks should be considered to accommodate greater tolerances of linear explosive lengths.

Installation Procedure Verification

Because of the criticality of shroud separation systems performance to mission success, it is extremely important that system installation and checkout procedures be developed in detail and verified prior to flight system installation. For the Payload Shroud, these procedures were developed, documented, and verified during full-scale separation testing. Future programs should continue to make procedure development/verification a primary test objective.

Separation Devices Transfer and Manifold Tubing

Multiple torque applications to tubing connectors were determined to be required procedurally to assure non-leakage of the PS transfer and manifold tubing. Future designs should consider use of improved tubing connections to eliminate [illegible] need for multiple torque applications.

Rain Testing

Where an article, because of its configuration and rigorous design requirements, requires extensive sealing to preclude moisture, precipitation or driven rain from entering the interior areas, it is recommended that complete rain tests under simulated conditions be conducted to assure that all design requirements are met.

Paint

A cosmetic problem existed with the white exterior paint utilized on the Payload Shroud. After painting, and during an extended time interval, the paint gradually discolored slightly so that areas which necessitated touchup were overly prominent in the finished article. Although this in no way affected the performance of the finish, it is recommended that investigation be considered to determine if this discoloration is due to specific atmosphere conditions or is inherent. Under either condition, if control is not feasible, possible other finishes should be investigated.